Binocular Vision Anomalies and Normative Data (BAND) of Binocular Vision Parameters among School Children Between 7 and 17 Years of Age in Rural and Urban Tamilnadu

THESIS

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By

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CERTIFICATE

This is to certify that the thesis entitled **"B**inocular Vision **A**nomalies and **N**ormative **D**ata (Band) of Binocular Vision Parameters Among School Children Between 7 And 17 Years Of Age in Rural and Urban Tamilnadu" and submitted by **Jameel Rizwana Hussaindeen -** ID No **2009PHXF700H** for award of Ph.D. of the Institute embodies original work done by her under my supervision.

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LIST OF ABBREVIATIONS

AA	–	Amplitude of accommodation
ABS	–	Academic behavior survey
AE	–	Accommodative excess
AF	–	Accommodative facility
AI	–	Accommodative insufficiency
AIF	–	Accommodative infacility
AT	–	Accommodative target
BAND	–	Binocular vision anomalies and normative data
CE	–	Convergence excess
CI	–	Convergence insufficiency
CISS	–	Convergence insufficiency symptom survey
CPM	–	Cycles per minute
DE	–	Divergence excess
DI	–	Divergence insufficiency
FVD	–	Fusional vergence dysfunction
MEM	–	Monocular estimate method
MIM	–	Muscle imbalance measure
NFV	–	Negative fusional vergence
NPA	–	Near point of accommodation
NPC	–	Near point of convergence
NSBVA	–	Non-strabismic binocular vision anomaly
PFV	–	Positive fusional vergence
PL	–	Pen light
ROC curve	–	Receiver operating characteristic curve
VF	–	Vergence facility
VR QOL	–	Vision related quality of life

CHAPTER 1

INTRODUCTION

Binocular vision (BV) testing is an important aspect of vision testing, and normal BV is necessary for efficient reading skills in children and adults. BV anomalies have been linked to impaired academic performance in children (AOA., 2010; Flax, 1994). To the best of our knowledge, there is no prevalence data for BV anomalies among children in the Indian literature. Also, to classify children as normal or abnormal as indicated by various authors (Scheiman et al., 2014), it is necessary to know the normal mean values for a battery of different tests conducted as part of BV assessment. In India, the diagnosis of BV anomalies is currently based on the Caucasian normative values from Morgan et al. (1944) and Duane et al., (1926) as compiled by Scheiman et al (2014). Ethnicity based differences in BV parameters have been reported in the literature (Chen et al., 2010). Thus, it becomes more appropriate to have ethnicity based data in the clinical decision making process. Hence, we aimed to study the prevalence of BV anomalies among school children in Tamilnadu, India, along with the estimation of normative data for BV parameters in this population.

Estimates of BV anomalies among school children will help in planning appropriate intervention so that efficient BV and efficient reading can be achieved, thus improving the Vision related quality of life (VR-QOL) of children. The obtained normative data could also benefit the clinical practice and management of BV anomalies.

1.1 LITERATURE REVIEW

According to the American Optometric Association, (2010) diagnosis and treatment of BV and accommodation anomalies should be a priority for the entire pediatric population. It also states that accommodative and vergence dysfunctions can significantly impair the reading performance of a child, especially after the third grade, as a result of increasing visual demands of the child. More than racial and socioeconomic factors, accommodative and vergence dysfunctions (termed as non-strabismic BV anomalies, NSBVAs) are better predictors of academic performance among school children (Palomo-Alvarez et al., 2010).

NSBVAs were found to be more common among school children between 9 and 13 years (Palomo-Alvarez et al., 2008, 2010) and can significantly impair the academic performance of children; therefore, normal BV is important for efficient and comfortable reading (Maples, 2003; Shin et al., 2009; Eames., 1934; Stein et al., 1988). Most importantly, children may not complain, as they do not realize that they need to read comfortably. Studies have shown that subjects with lower heterophoria have better sporting performance and depth perception compared to non-athletes (Graybiel et al., 1955). Thus, it can be hypothesized that the sporting ability of the child may also be affected as a result of BV dysfunctions, as better binocular skills contribute to better athletic performance. Because of the hidden (latent) nature of NSBVAs, detection without clinical tests, based only on observation, as in manifest squint, is not possible. These data and the literature (Palomo-Alvarez et al., 2008, 2010; Maples, 2003; Shin et al., 2009; Eames., 1934; Stein et al, 1988) from various sources emphasize the need for screening for these anomalies.

"*Optimizing the probability of early detection of eye disorders in children is crucial for successful clinical management*" (Logan et al., 2004).Generally, most vision screening programs focus on screening for refractive errors and other significant visual/ocular morbidities. Unless specifically tested for, BV anomalies can be missed out in routine screening or even in clinical practice where the focus is more on visual acuity and related skills. To the best of our knowledge, there exist no data in the Indian literature on the prevalence of BV anomalies. This data is important to understand the visual morbidity due to BV disorders and also to plan further intervention to improve the visual performance through appropriate measures.

1.1.1 Standard clinical tests for the diagnosis of binocular vision anomalies

The standard clinical tests used to diagnose accommodative abnormalities are discussed below (Scheiman et al, 2014). These abnormalities include, but not necessarily limited to, accommodative insufficiency, infacility, ill-sustained accommodation, and accommodative excess. Direct measures of accommodation testing used to diagnose accommodative anomalies include the testing of

- Near point of accommodation (NPA)
- Monocular estimation method (MEM) retinoscopy
- Monocular accommodative facility

The indirect measures of accommodation testing include

- Negative and positive relative accommodation (NRA and PRA) measurements
- Binocular accommodative facility testing
- Vergence amplitudes and vergence facility testing

In the sequential management approach of accommodative dysfunction, optical correction of ametropia is the first step, followed by added lenses and vision therapy (VT). Prisms and surgery are generally not indicated in accommodative anomalies. Treatment modalities for these conditions, and how BV tests help to decide if lenses, prisms, and/or VT are indicated, are described in the following for specific conditions.

1.1.2 Accommodative insufficiency

Accommodative insufficiency is a condition where patients are found to have difficulty stimulating accommodation. The most common symptoms generally specific to near vision tasks in accommodative insufficiency include blur, headaches, eyestrain, fatigue, difficulty in focusing from one distance to another, reading difficulty, etc. In accommodative insufficiency, the dynamics of accommodation remain generally intact.

Direct diagnostic signs in accommodative insufficiency include

- Reduced accommodative amplitudes (AAs) of 2D or more, as per Hofstetter's minimum amplitude of accommodation (AA) calculations [15–0.25 (age)]
- Difficulty clearing –2.00 D lenses in monocular accommodative facility testing <4.5 cycles per minute (CPM)
- High MEM (monocular estimation by retinoscopy) finding of >+0.75 D

The indirect diagnostic signs in accommodative insufficiency include

- Difficulty clearing −2.00 D lenses in binocular accommodative facility testing <2.5 CPM
- Reduced PRA finding of <−1.25 D

1.1.2.1 Treatment Modality

1.1.2.1.1 Lenses

Prescription of uncorrected refractive error is the first step in the treatment. Correction of small degrees of hyperopia, astigmatism, and minimal anisometropia can significantly influence the accommodative system to respond positively to treatment. Uncorrected hyperopia would be reflected as reduced AA, difficulty with minus lenses in accommodative facility testing, high lag in MEM finding, and secondarily reduced PFV values at near.

1.1.2.1.2 Added lenses

Use of added plus lenses are beneficial in accommodative insufficiency to restore the reduced NPA. The amount of plus lenses can be decided based on the relative accommodation findings (high NRA values and low PRA values), MEM values (high lag of accommodation), and the phoria status (esophoria or exophoria). Use of added lenses is indicated when the refractive error is insignificant with other associated findings as mentioned.

1.1.2.1.3 Vision therapy (VT)

VT can be generally combined with or initiated following the prescription of uncorrected refractive error or added plus lenses. VT is aimed at improving the AA, positive fusional vergence (PFV) amplitudes, accommodative facility, and vergence facility.

1.1.2.2 Treatment Outline

Treatment involves one or more of the following:

- Training of accommodative amplitudes
- Training of voluntary convergence

- Enhancement of relative accommodation ranges
- Training PFV and negative fusional vergence (NFV) amplitudes
- Training accommodative and vergence facility
- Accommodative procedures integrated with vergence procedures, oculomotor skills, and visual information processing in the final phase

1.1.3 Ill-sustained accommodation

In Ill-sustained accommodation, the accommodative amplitudes are normal but the patient will have difficulty in sustaining the accommodative demand. The symptoms and signs are similar to accommodative insufficiency except for normal AA. The patient reports fatigue after repeated accommodative stimulation. The treatment protocol is also similar to that of accommodative insufficiency.

1.1.4 Accommodative infacility

Accommodative infacility is a condition where the accommodative responses are delayed for stimulation and relaxation. There is considerable lag between the accommodative stimulus and response. Blurred distance vision after prolonged near work, and vice versa, is the most reported symptom. Other symptoms include headaches, eyestrain, fatigue, difficulty in focusing from one distance to another, difficulty sustaining close work, etc. The AA and MEM findings are generally normal in accommodative facility testing.

The direct diagnostic sign in accommodative facility is

- Difficulty clearing ±2.00 D lenses in monocular accommodative facility testing <4.5 CPM

The indirect diagnostic signs include

- Difficulty clearing ±2.00 D lenses in binocular accommodative facility testing <2.5 CPM
- Reduced NRA (<+1.50 DS) and PRA finding (<−1.25 DS)

1.1.4.1 Treatment Modality

1.1.4.1.1 Lenses

Prescription of uncorrected refractive error is the first priority. Correction of small degrees of hyperopia or myopia, astigmatism, and minimal anisometropia can significantly influence the accommodative system to respond positively to treatment.

1.1.4.1.2 Added lenses

Use of added plus lenses are generally not indicated in accommodative infacility. Reduced NRA and PRA values, normal MEM finding, and normal AA do not necessitate the need for added lenses.

1.1.4.1.3 Vision therapy

VT can be generally combined with or given following the prescription of uncorrected refractive error. VT is aimed at improving the dynamics of accommodative response, accommodative facility, NFV and PFV amplitudes, and vergence facility.

1.1.4.2 Treatment Outline

Treatment involves one or more of the following:

- Training of accommodative facility
- Training of voluntary convergence and divergence
- Enhancement of the relative accommodation ranges
- Training PFV and NFV amplitudes
- Training vergence facility
- Accommodative procedures integrated with vergence procedures, oculomotor skills, and visual information processing in the final phase

1.1.5 Accommodative excess

Accommodative excess is a condition in which the patient has difficulty stimulating accommodation. The most common symptom include blurred vision, headaches, eyestrain, fatigue, difficulty concentrating on reading tasks, etc. The symptoms start after sustained near work associated with variable blurred vision and worsen toward the end of the day.

The direct diagnostic signs in accommodative excess include

- Difficulty clearing +2.00 D lenses in monocular accommodative facility testing <4.5 CPM
- Low MEM finding <Plano
- Variable refractive or accommodative findings

The indirect diagnostic signs include

- Difficulty clearing ±2.00 D lenses in binocular accommodative facility testing <2.5 CPM
- Reduced NRA finding <+1.50 DS

Convergence insufficiency (CI) can give rise to secondary accommodative excess. In such cases, the symptoms and signs will be overlapping with that of CI. The treatment modality and treatment outline is the same as that of accommodative infacility.

The following section discusses the standard clinical tests used in the diagnosis of vergence abnormalities. These abnormalities include, but not necessarily limited to, CI, convergence excess, divergence insufficiency, and divergence excess (DE). Treatment modalities for these conditions and how these tests help to decide whether lenses, prisms, and/or VT is indicated are also discussed.

The specific tests used in the diagnosis of BV anomalies include testing for near point of convergence (NPC), NPA, accommodative convergence/accommodation (AC/A) ratio, and phoria status.

Direct tests of non-strabismic vergence anomalies include but not restricted to

- Testing of vergence amplitudes and vergence facility

Indirect tests of non-strabismic vergence anomalies include but not restricted to

- Testing of relative accommodation measurements
- Accommodative facility testing
- MEM retinoscopy

Common symptoms reported in non-strabismic vergence anomalies are specific to near-visual tasks and tasks requiring sustained concentration. These include, but are not limited, to headaches, eyestrain, eye pain, fatigue, diplopia, monocular eye closure, and variable blurred vision. Prescription of any significant refractive error is the first management consideration in all BV anomalies. Vertical prism prescriptions if any are also recommended prior to VT.

1.1.6 Convergence insufficiency

Convergence Insufficiency (CI) refers to the inability to sustain convergence on prolonged near visual tasks. Table 1.1 summarizes the clinical tests used in the diagnosis of CI and the expected findings.

TABLE 1.1 Clinical tests and expected findings in CI

Tests to Diagnose CI	**BV Findings**
Cover test	Exophoria at near >6 prism diopters
NPC	Remote; Recedes further on repeated testing (>10 cm); Poor recovery (>17.5 cm)
NPA	Generally normal; Reduced accommodative amplitudes (AA) of 2 D or more as per Hofstetter's minimum AA calculations [15–0.25 (age)] if CI is secondary to accommodative insufficiency (pseudo convergence insufficiency)
Positive fusional vergence (PFV)	Reduced PFV amplitudes at near in step vergence testing (Blur/Break/Recovery:<11/4/3)
Fixation disparity testing/associated phoria	Exo fixation disparity
AC/A ratio	Low (<3/1)
NRA	<+1.50 DS
Binocular accommodative facility testing	Difficulty with plus lenses (<2.5 CPM); Difficulty with minus lenses in monocular and binocular accommodative facility testing if accommodative insufficiency is the primary cause
MEM retinoscopy	Low values (<plano); Increased lag of accommodation if accommodative insufficiency is the primary cause

The recommended choice of treatment in CI is VT. After prescription of appropriate refractive correction, in-office VT combined with home reinforcement is the treatment of choice. Added plus lenses are indicated in CI secondary to accommodative insufficiency, since convergence generally improves with plus lenses in accommodative insufficiency. Prism prescriptions are considered in elderly patients and in patients with complex disorders such as acquired brain injury. Relieving prisms can be used to ease the process of VT in the initial stages.

1.1.6.1 Treatment Outline

Treatment involves one or more of the following:

- Training of voluntary convergence
- Enhancement of NPC
- Training of PFV amplitudes
- Enhancement of accommodative amplitudes
- Training of vergence facility
- Enhancement of relative accommodation ranges
- Training of NFV amplitudes
- Vergence procedures integrated with oculomotor skills and visual information processing in the final phase

1.1.7 Convergence excess

Convergence excess (CE) refers to a tendency to over converge at near. The clinical findings in CE are enumerated in Table 1.2.

After the prescription of any significant refractive error, added plus lenses are indicated in CE due to the high AC/A ratio. The amount of plus lenses can be decided based on the AC/A ratio, relative accommodation measurements, and MEM finding. VT is indicated to train divergence and esophoria.

1.1.7.1 Treatment Outline

Treatment includes one or more of the following:

- Training of voluntary divergence

TABLE 1.2 Clinical tests and expected findings in CE

Tests to Diagnose Convergence Excess	Findings
Cover test	Esophoria at near >2 PD
NFV	Reduced NFV amplitudes at near in step vergence testing (Blur/Break/Recovery:<8/16/7)
AC/A ratio	High (>7/1)
PRA	Low (≤ –1.25 DS)
Binocular accommodative facility testing	Difficulty with minus lenses in binocular accommodative facility testing (<2.5 CPM)
MEM retinoscopy	High (>+0.75 DS)
Fixation disparity	Eso

- Training of NFV amplitudes
- Enhancement of accommodative amplitudes
- Training of vergence facility
- Enhancement of relative accommodation ranges
- Training of PFV amplitudes
- Vergence procedures integrated with oculomotor skills and visual information processing in the final phase

1.1.8 Divergence insufficiency

Divergence insufficiency (DI) refers to the tendency to over-converge or inadequately diverge for distance.

There are no cut-off values available for the diagnosis of basic esophoria, exophoria, DE, divergence insufficiency, or fusional vergence dysfunction; hence only the generic criteria are given (Table 1.3).

Prescription for any significant refractive error is the first step. Added plus lenses are generally not beneficial due to the low AC/A ratio. However, a trial of plus lenses can be decided based on the eso component. Plus lenses in combination with horizontal prisms can be tried to reduce diplopia for distance. The amount of prisms can be calculated using the associated phoria measurements. VT is indicated to train divergence and esophoria.

TABLE 1.3 Generic diagnostic criteria for DI

Tests to Diagnose Divergence Insufficiency	Findings
Cover test	Esophoria more for distance than for near
NFV	Reduced NFV amplitudes at distance in step and smooth vergence testing; difficulty with base in (BI) prisms in jump vergence testing
AC/A ratio	Low
Fixation disparity	Eso disparity at distance

1.1.8.1 Treatment Outline

- Training of voluntary divergence
- Training of NFV amplitudes
- Enhancement of accommodative amplitudes
- Training of vergence facility
- Enhancement of relative accommodation ranges
- Training of PFV amplitudes
- Vergence procedures integrated with oculomotor skills and visual information processing in the final phase

1.1.9 Divergence excess

Divergence excess (DE) refers to the inability to converge adequately for distance. There is a greater amount of exophoria at distance than at near, and the deviation is intermittent and tends to vary with attention. Good stereopsis and the absence of amblyopia are other characteristic features of DE (Table 1.4).

Prescription of significant refractive error, especially myopic errors, significantly improves the angle of deviation at distance. Added minus lenses can be prescribed in preschool children to control the deviation at distance. Accommodative demand for near is generally not required in preschool children and hence it is useful. Added minus lenses are indicated in the presence of normal AA , high AC/A ratio, good NFV amplitudes, exophoric component for distance, and difficulty with plus lenses in accommodative facility testing.

TABLE 1.4 Generic diagnostic criteria for DE

Tests to Diagnose Divergence Excess	Findings
Cover test	Exophoria more for distance than for near; Intermittent deviation, variable
PFV	Reduced for distance
Fixation disparity testing/ associated phoria	Exo fixation disparity
AC/A ratio	High
Accommodative facility testing	Fails plus lenses binocularly

1.1.9.1 Treatment Outline

Treatment includes one or more of the following:

- Training of voluntary convergence at distance and near
- Training to eliminate suppression and developing diplopia awareness
- Training of PFV amplitudes at distance and near
- Enhancement of accommodative amplitudes
- Enhancement of near point of convergence
- Enhancement of stereopsis
- Training of vergence facility
- Training of NFV amplitudes
- Vergence procedures integrated with accommodative procedures, oculomotor skills, and visual information processing in the final phase

1.1.10 Basic exophoria

- Exophoria of equal magnitude at far and near
- Normal AC/A ratio
- PFV reduced at far and near

1.1.11 Basic esophoria

- Esophoria of equal magnitude at far and near

- Normal AC/A ratio
- NFV reduced at far and near

1.1.12 Fusional vergence dysfunction

- Reduced PFV and NFV at far and near
- Orthophoria or a low degree of exophoria or esophoria at far and near

The diagnostic criteria as stated above have been arrived from consensus and compilation of clinical data. There is considerable lacuna in the literature in this area. These include the absence of community based normative data for the population under investigation. The prevalence of NSBVA in many studies have adopted the criteria stated above. A few authors (Cacho-Martinez et al., 2010; Lara et al, 2001) have modified this criteria but again, based on consensus rather than a derived cut-off point. It is important to note that the validity of these diagnostic criteria lies in the normative cut-off points derived from the population.

1.1.13 Normative data for BV parameters

"Normative data is data from a reference population that establishes a baseline distribution for a score or measurement, and against which the score or measurement can be compared. Normative data is typically obtained from a large, randomly selected representative sample from the wider population (Campbell, 2013)." Normative data in the context of BV have been described as parameters of accommodation and vergence among subjects with normal ocular health and absence of near visual symptoms or difficulty while performing the specific binocular vision test. For a few important BV parameters, the available normative data in the literature is summarized below.

Near-point of convergence (NPC) is an important vergence parameter that is used as the main criterion in the diagnosis of CI. Literature on normative data for NPC shows variations in the reported data primarily due to the difference in testing methods. The standard push-up technique with a penlight is believed to measure the subject's fusional convergence independent of accommodation (Pang et al, 2010). Therefore, measurement of NPC with an accommodative target and a penlight with red and green filter will improve the sensitivity of the test in the diagnosis of CI (Pang et al., 2010; Maples et al, 2007). No definite gender predilection for NPC has been reported in most of the studies (Anderson et al., 2011; Scheiman et al, 2003). The general normative range for NPC agreed upon so far is 5–7 cm for young adults (Scheiman et al, 2003), and 6–10 cm for school children, as shown by Hayes et al (1998), the clinical difference being insignificant between all the cut-offs. NPC is a dynamic factor depending on BV factors like phoria, fusional vergence ranges, and accommodative parameters, and developmental factors such as inter-pupillary distance. Therefore, a clear understanding of all the dynamic factors becomes necessary to comment on this variation.

The NPA is the commonest and most often the only criterion used in the diagnosis of accommodative anomalies in general clinical practice. The insufficiency in accommodative amplitudes is determined based on an age-related expected finding calculated using Hofstetter's equation derived from Donder's (1864) and Duane's (1912) data. Many investigators have used cross-sectional studies to confirm that the AA declines with age (Rambo, 1957; Rambo & Sangal., 1969; Chattopadhyay & Seal, 1984). The Indian references concerned with this parameter are primarily in the adult age range.

Rambo et al (1957) measured the AA from 1340 eyes in the age group 10–50 years. They found that there were rapid falls in the amplitude at 15 and 37.5 years in the Indian population. They had also found no statistical difference between the amplitudes of left and right eyes. Chattopadhyay and Seal (1984) measured the NPA from 800 eyes of 400 subjects between 6 and 65 years in the Indian state of Bengal and came up with the following relationship between age and the average AA:

$$\text{Age} = 35.5 - 4.2\,(\text{AA} - 3.89)$$

From this equation, it is easy to see that the AA comes to 3 D at about 39 years of age. Chattopadhyay and Seal (1984) have also reported two dips in the accommodative amplitudes, one at 16–20 age range and other between 41 and 50 years. Abraham et al (2005), measured the AA in the right eye of 316 consecutive patients in the age group 35–50 years visiting their clinic over a 1-year period. They found that the mean AA in the 35–40 year age group was 2.75 D for emmetropes, 3.71 D for myopes, and 2.73 D for hyperopes. A compilation of the existing Indian literature (Rambo, 1957; Rambo & Sangal., 1969; Chattopadhyay & Seal., 1984; Abraham et al, 2005) suggests that the accommodative amplitudes of Indian subjects are relatively low compared to the existing norms based on

Hofstetter's (1944) expected AA. When compared to Hofstetter's average expected AA, the accommodation amplitudes are lower by about 2–4 D.

With respect to the measurement techniques, push-up technique has been considered as a standard due to its robustness. In the push-up technique, the near target equivalent or one line better than the best corrected near visual acuity is moved closer to the eyes until a sustained blur is noted. The readings in metrics are converted to diopters to get the NPA. Though this technique has problems of varying magnification of the target due to proximity, it is still followed routinely in the clinical setup. A modification suggested by Scheiman and Wick (2014) to overcome this limitation includes decreasing of the near target size as it is taken closer to the patient's eyes.

Heterophoria refers to the binocular status of the eyes under dissociated conditions, and fusional vergence refers to the binocular reserves that control the phoria. Heterophoria testing is an important part of routine optometric testing and diagnosis in BV testing. Among the various different techniques available, such as von-Graefe, prism cover test, Maddox rod testing, etc., the modified Thorington (MT) method has been recommended by many authors (Scheiman et al., 2014; Schroeder et al., 1996; Rainey et al, 1998) for its simplicity, control of accommodation, and high reliability and repeatability (Rainey et al, 1998). Also, this test is useful for children in whom measurement of phoria using prisms is difficult, as this test eliminates the need for prism and thereby prism-induced blur in one eye that could influence the accommodative demand of the target. The normative parameters for phoria are based on Morgan's (1944) normative data, which states a mean (SD) horizontal phoria ranging between 1(2) and 3(2) prism diopters (PD) exophoria at distance and near, respectively (Table 1.5). The vertical phoria ranges are within 1 PD of hyper and hypophoria.

Fusional vergence measurements can be made using Synoptophore or Risley prisms (smooth vergence) in a phoropter. The well-known Morgan's normative data (1944) is based on phorometric measurements of accommodative and vergence parameters and hence limited for referencing with free-space measurements. Step vergence measurements using a prism bar in free space is recommended for the purpose of observing objective eye movements even though verbal responses are not reliable. The mean (SD) for vergence parameters have been proposed by various authors (Table 1.5), and the reason for the difference is attributed primarily to the measurement technique. Also, among the

TABLE 1.5 Normative data for heterophoria and vergence amplitudes from existing literature

Author	Sample size	Age (in years)/ Grade	Method	Phoria (in PD) (SD)		Vergence values (Blur/break/recovery)			
				Distance	Near	Distance NFV	Near NFV	Distance PFV	Near PFV
Morgan (1944)	800	Pre-presbyopic adults	Phorometry	1 exo (2)	3 Exo (5)	x/7(3)/4(2)	13(4)/21(4)/13(5)	9(4)/19(8)/10(4)	17(5)/21(6)/11(7)
Scheiman et al (1989)	386	6–12	Step vergence	No data	No data	No data	x/12(5)/7(4)	No data	x/23(8)/16(6)
Jimenez et al (2004)	1015	6–12	MT/ Step vergence	0.6 eso (2)	0.4 exo (3)	x/6(2)/4(2)	x/11(3)/7(3)	x/17(7)/11(6)	x/18(13)/8(6)
Lyon et al (2005)	453 426	1st Grade 4th Grade	MT/Step vergence	0 (2)	1 Exo (4)	x/7(4)/4(3)	x/16(10)/7(5)	x/12(6)/7(4)	x/21(11)/13(8)

various BV parameters, vergence amplitude has been shown to have reduced repeatability and higher intra-observer variability (Rouse et al, 2002).

Vergence facility refers to the assessment of the dynamics of the vergence system to rapidly alternate between vergence demands, and thus represents the sustainability of the vergence system (Scheiman et al, 2014). In 20 subjects aged between 18 and 35 years, Gall et al (1998, 2003) recommended a value of 15 CPM with 12 base out/3 base in vergence flippers. They also recommend that this magnitude of prisms combination is best at discriminating symptomatic and asymptomatic subjects.

Accommodative facility testing represents the dynamics of the accommodation system to stimulate and relax accommodation to rapid changes in stimulus demand. There is paucity of normative data for this parameter in the literature. Scheiman et al (2014), recommends a mean (SD) of 7 (2.5) and 5 (2.5) CPM for children aged 8 and above for monocular and binocular accommodative facility, respectively, with a standard magnitude of ±2.00 accommodative flippers. There is significant decline in accommodative facility with age which therefore demands normative data for specific age groups.

Accommodation lag as measured using monocular estimate method (MEM) has been shown to be a clinically useful tool to understand the accommodative response of individuals with NSBVA. The mean (SD) values proposed for MEM retinoscopy is +0.50 (0.25) D (Scheiman et al, 2014).

For the AC/A ratio, heterophoria method and gradient stimulus methods have been utilized in most of the studies. There is considerable agreement that the AC/A ratio remains relatively stable across ages with a mean (SD) of 5 (1) and 2.2 (0.8) for the calculated and gradient methods, respectively (Sen & Malik, 1972).

Extensive literature is available for the normative data parameters for vergence parameters in Caucasian population (Scheiman et al., 2014; Morgan., 1944; Scobee & Green, 1948). Some clinical data suffer from poor reliability, as pointed out by Rutstein and Daum (1998). The factors that affect reliability include smaller sample size, sampling strategies, absence of population based studies, lack of standardized criteria for diagnosis, and variability in measurements techniques. For example, Scheiman et al (1989), used a suppression check for fusional vergence measurements, whereas Lyon et- -al (2005) did not. Likewise, Jimenez et al (2004) employed chin rest and head rest while making the near vergence measurements, whereas the other authors had carried out the test under conventional clinical setup without chin rest. Comparisons of normative data from different ethnicity are primarily limited by small sample size in certain population and also limited data in the adult sample.

There is no Indian literature pertaining to the pediatric age group, to the best of our knowledge, on the normative data for BV anomalies. The available earlier Indian references have not changed the clinical reference due to various factors such as small sample size, limited age range, hospital-based samples, variations in measurement techniques, and limited or no information on confounding factors.

1.1.14 Prevalence of binocular vision anomalies

To the best of our knowledge, there exist no data in the Indian literature on the prevalence of BV anomalies. This data is important to understand the visual morbidity due to these disorders. Recent population based studies (Jang & Park., 2015; Wajuhian, 2015) in other countries have found that the prevalence of NSBVA is 30% among school children. Increasing near visual demands and changing lifestyle could be the influential factors for the increasing prevalence. CI is the most common type of NSBVA, ranging between 15% and 18%. This demands the need for updated prevalence data in India, as most current data is more than a decade old.

Certain hospital-based reports state varied frequencies of CI from 3.6% (Dhir, 1961) to 7.7% (Deshpande & Ghosh, 1991). Among school children in Nepal, the reported prevalence of CI is 2.49% (Marasini et al, 2010). The prevalence of NSBVAs has been reported to be as high as 56.2% in the general adult Caucasian population between 18 and 38 years (Montes-Mico, 2001) and 15.3% among university students (Porcar & Martinez-Palomera, 1997).

NSBVAs were found to be more common among school children between 9 and 13 years (Scheiman et al, 1996). Also, due to the hidden (latent) nature of NSBVAs, detection without clinical tests just based on observation as in manifest squint is not possible. Convergence insufficiency (CI) and accommodative insufficiency (AI) were common in school children between 8 and <15 years of age and these children were more symptomatic than the children in the normal BV group (Palomo-Alvarez et al., 2008, 2010; Maples, 2010). According to a study by Borsting et al (2003), 79% of children who were diagnosed with CI have AI as the primary or co-morbid cause; similarly, 4.7% and 3.3% of elementary school children have AI as the primary diagnosis and co-morbid cause respectively, resulting in increased symptoms (Marran et al, 2006). But most importantly, children may not realize that reading should be a comfortable experience. In addition, because of NSBVA cannot be detected without clinical tests, parents and teachers were unable to determine if there is a vision problem just based on observation. Children with reading difficulties present with poorer accommodative facility, vergence facility, near point of convergence (NPC) and accommodation and slower reading speed compared to age matched controls (Dusek et al, 2010). Appropriate spectacle prescription and vision therapy play a key role in the remediation of symptoms in these children (Scheiman et al., 2010; Scheiman et al., 2008; Abdi & Rydberg, 2010)

1.1.15 Binocular vision anomalies and vision-related quality of life

Can NSBVA impair the vision-related quality of life (VR-QOL) and academic performance of children?

Poorer VR-QOL scores have been reported in subjects with NSBVA in many studies (Daugherty et al., 2007; Abu Bakar et al., 2012; Borsting et al., 2003a; Rouse et al., 2003; Rouse et al., 2009; Scheiman et al., 2005). Children with CI are reported to have academic difficulties compared to children with normal BV.

Abu-Bakar et al (2012) have come up with a modified College of Optometrists in Vision Development (COVD) QOL questionnaire to assess the QOL in children with BV anomalies and reading dysfunctions. This modified questionnaire has been Rasch-tested and found to be ideal in identifying children with BV anomalies. The sensitivity and specificity of the questionnaire in identifying vision disorders in special children was 78% and 80%, respectively. But the predictive validity of this questionnaire in mainstream schools was low and thus recommended only for the special population. Another validated VR-QOL in the Caucasian ethnicity is the Convergence Insufficiency Symptom Survey (CISS) designed by the convergence insufficiency treatment trial (CITT) study group (Scheiman et al., 2005; Rouse et al, 2009). This questionnaire with 15 items grades the severity of visual symptoms in CI on a scale 0–4, thus giving a score ranging between 0–60, with higher scores indicating more symptoms. The CISS gives a two-factor analysis, on the presence or absence of symptoms, and on the frequency of symptoms. The

CISS has been shown to identify children with CI in the general population and in clinical settings. The mean (SD) scores in CI children were 29.8 (9) compared to 8.1 (6.2) in the normal BV group.

The Academic Behavior Survey (ABS) (Rouse et al, 2009) is a six-item questionnaire designed by the CITT study group to evaluate the academic performance behavior in symptomatic CI with and without parent-reported attention deficit hyperactivity disorder (ADHD) compared to normal BV. This is scored on an ordinal scale ranging between 0 and 4, with a maximum score of 24. Children with CI and a parent report of ADHD had higher scores with ABS than children without a report of ADHD, and lower scores were reported in children with normal BV.

Higher scores on both ABS and CISS suggest increased visual symptoms. Both ABS and CISS have been found to be valid tools with good internal consistency in the CITT study sample.

1.1.16 Impact of vision therapy on NSBVA

Published reports have found that VT is efficacious in improving the QOL of children with BVAs (Scheiman et al, 2005).

The recent CITT study group (Scheiman et al., 2008) emphasized the importance on in-office VT as the gold standard treatment option and found conventional home-based training such as pencil push-up exercises to be equivalent to placebo treatment.

In a community setup, with both limited human and facility resources, the feasibility of comprehensive VT as in a clinical setup is questionable. There is no data to the best of our knowledge on innovative models of VT suitable at the community level.

1.2 GAPS IN THE LITERATURE

To classify children as normal or abnormal as indicated by various authors (Scheiman et al, 2014), it becomes necessary to know the normal mean values for a battery of different tests conducted as part of BV assessment. Extensive literature is available for the normative data parameters for vergence and accommodation parameters in Caucasian population. If the difference in ethnicity and race are taken into account, clinical practice based on the Caucasian data compiled from various authors for different age groups might complicate the interpretation and management. Racial differences in BV parameters have been reported in the literature (Chen & Iqbal, 2000), and this demands the need for a separate Indian data bank. For this reason, comprehensive data of accommodation and vergence parameters in a large population across different age groups is required. Based on this normative data, an estimate of the prevalence of binocular anomalies can be done prospectively in community and clinical settings.

Estimates of BV anomalies among school children would help in planning appropriate assessment and intervention. Moreover, the normative data will have significant implications for the clinical practice and management of BV anomalies.

Therefore, the objectives of this study were

1. To determine normative data of BV parameters among school children
2. To estimate the prevalence of BV anomalies among school children in rural and urban Tamilnadu
3. To provide vision therapy for children identified as having BV anomalies and to assess the impact of vision therapy on BV parameters
4. To arrive at the minimum test battery needed to pick up BV anomalies in a community set up and to reassess prevalence in the community to validate the minimum test battery
5. To understand the utility of the CISS and ABS and its association with NSBVA in the community

Also as part of this study, understanding the utility of the CISS and estimating the prevalence of convergence insufficiency in a hospital based set-up was also aimed at. These works are presented in chapter 7 and 8.

1.3 IMPLICATIONS OF THIS RESEARCH

The obtained normative data from this study could serve as a valuable reference in the clinical practice and management of BV anomalies. It will also provide an insight into the developmental trend of vergence and accommodative parameters in the Indian population. Estimates of BV anomalies among school children will help in planning appropriate interventions so that efficient BV and efficient reading can be achieved. This study will also help us to understand the relationship between NSBVA, academic performance, and VR-QOL among school children.

Using multiple tests to diagnose a condition limits the viability of the program in community setups. Analyzing the sensitivity of the different tests used in this study can provide insight into the minimum test battery that is needed in a screening setup to detect BV anomalies. This will ensure that the model is sustainable and can be implemented as part of the regular screening protocol. Also, innovative school based model of vision therapy planned as part of this study could help alleviate the visual morbidity of NSBVA in the community.

Further chapters will present the methodology of the study, and the outcomes of the research.

CHAPTER 2

BINOCULAR VISION ANOMALIES AND NORMATIVE DATA (BAND) IN TAMILNADU – STUDY DESIGN AND METHODS

2.1 METHODOLOGY

This project has been approved by the Institutional Review Board of Vision Research Foundation (VRF) and follows the guidelines proposed by declarations of Helsinki. The study consisted of four phases.

2.1.1 Phase I: Training Program

Two optometrists who participated in the study were trained and assessed for intra-examiner agreement with the principal investigator of the study. The parameters of concern for the repeatability assessment include NPC with accommodative target, near point of accommodation (NPA), and distance and near fusional vergence amplitudes. The rest of the BV tests were carried out by a single examiner at study site. The repeatability cut-off for negative fusional vergence (NFV), positive fusional vergence (PFV), and NPC have been adopted from Rouse et al (2004). The BV assessment were performed on 30 subjects and the Altman–Bland agreement were determined (Altman & Bland, 1983). If the agreement for all the tests was not found to be within the clinically agreeable limits of test–retest variability, re-training was given and the same processes were repeated. Manual of Procedures was adopted for all the procedures to ensure uniformity (Appendix 1).

2.1.2 Phase II. Epidemiological Field Work

The principal investigator presented the details of the project to the school administration and written informed consent has been obtained from the school authorities, along with oral consent from the parent. A meeting was organized to explain the project and procedures to the parents. An awareness session on common ocular diseases and BV anomalies was presented to the students and teachers.

The field work for the study began in February, 2014 and was completed by December, 2015. The schools in rural and urban arms have been identified based on nonprobability convenience sampling depending on acceptance from the schools administration. After the sampling frame and unit (the list of students in every class) were identified, subject enrolment was carried out based on simple random sampling. Based on the calculated sample size in every age group, consecutive students were enrolled until the required sample was achieved.

2.1.2 a. Study zones

An area with a minimum population of approximately 5000, with a density of 400 per square kilometer and 75% of male population engaged in non-agricultural activities was termed as urban and the rest of the areas were defined as rural for the study, based on the Indian census definition (Indian district database, 2000).

In the rural arm, two schools were identified from villages of Tamilnadu, one from the Tiruvallur District and one from Sankarankoil, Tirunelveli District. In the urban arm, two schools were identified from Tambaram Municipality, Kanchipuram District, Tamilnadu.

2.1.2 b. Vision screening and eye examination

The steps involved in the vision screening process are listed in Table 2.1 and the inclusion and exclusion criteria are listed in Table 2.2.

2.1.3 Phase III A: Binocular Vision Screening Protocol

The pass criteria for the screening protocol (Jimenez et al, 2004) were

1. Visual acuity better than or equal to 20/30(6/9) at distance and near
2. No symptoms of asthenopia, eyestrain, blurred vision, and difficulty associated with reading
3. Stereo acuity >100 arc seconds (Randot stereo test)
4. No constant or intermittent strabismus as detected using the cover test

TABLE 2.1 Steps in the vision screening

Screening using a visual acuity cut-off of 6/9 using the ESO Pocket vision screener (Raja et al, 2014)
Ocular motility using the Broad H test
Pupillary assessment and torch-light examination for gross ocular abnormalities
Static retinoscopy and subjective acceptance using log MAR (**Log**arithm of the **m**inimum **a**ngle of **r**esolution) chart for children with refractive errors
Stereo acuity for near using Randot stereo plates
If a subject is found to have refractive error for the first time or if a change in refractive error of more than 0.50 D is detected during the refraction, glasses were prescribed and BV assessment were done after 2 weeks of glass prescription. Tolerance limits for refractive errors were adopted from the CITT protocol (Scheiman et al, 2005)
Referral of children with strabismus, amblyopia, and other ocular abnormalities to the base hospital
After vision screening, eye examination was done, followed by inclusion of subjects for prevalence and normative data based on the inclusion and exclusion criteria

TABLE 2.2 Inclusion and exclusion criteria

Inclusion Criteria	**Exclusion Criteria**
Subjects in the age between 7 and 17 years Best corrected visual acuity better than or equal to 6/9, N6	Ocular abnormalities/ strabismus (constant and intermittent) History of any previous intraocular/squint surgeries Self-reported history of ocular/head trauma Self-reported history of Juvenile diabetes

No cut-off was considered for NPC, accommodative amplitude, phoria, and vergence parameters as the main outcome was to estimate normative data for these parameters in the asymptomatic children. Subjects who failed the screening criteria were referred for further management; and subjects who passed the above-mentioned criteria were included for the study. But, this did not qualify the subject to have normal BV, until they clear the comprehensive BV assessment. Asymptomatic subjects who did not report any difficulty during the BV assessment were included for the normative data. A difficulty during testing is defined as subjective report of blur or diplopia with specific lenses or prisms, or symptoms of eye strain, headache, and eye pain. There could be subjects who were asymptomatic and have a BV anomaly and there could be subjects who have low level of symptoms but still have normal BV. These combinations were specifically looked for during the analyses and these subjects were reassessed prior to classifying them to one of the two groups of normal BV vs. NSBVA. The flow of the recruitment of subjects is depicted in Figure 2.1.

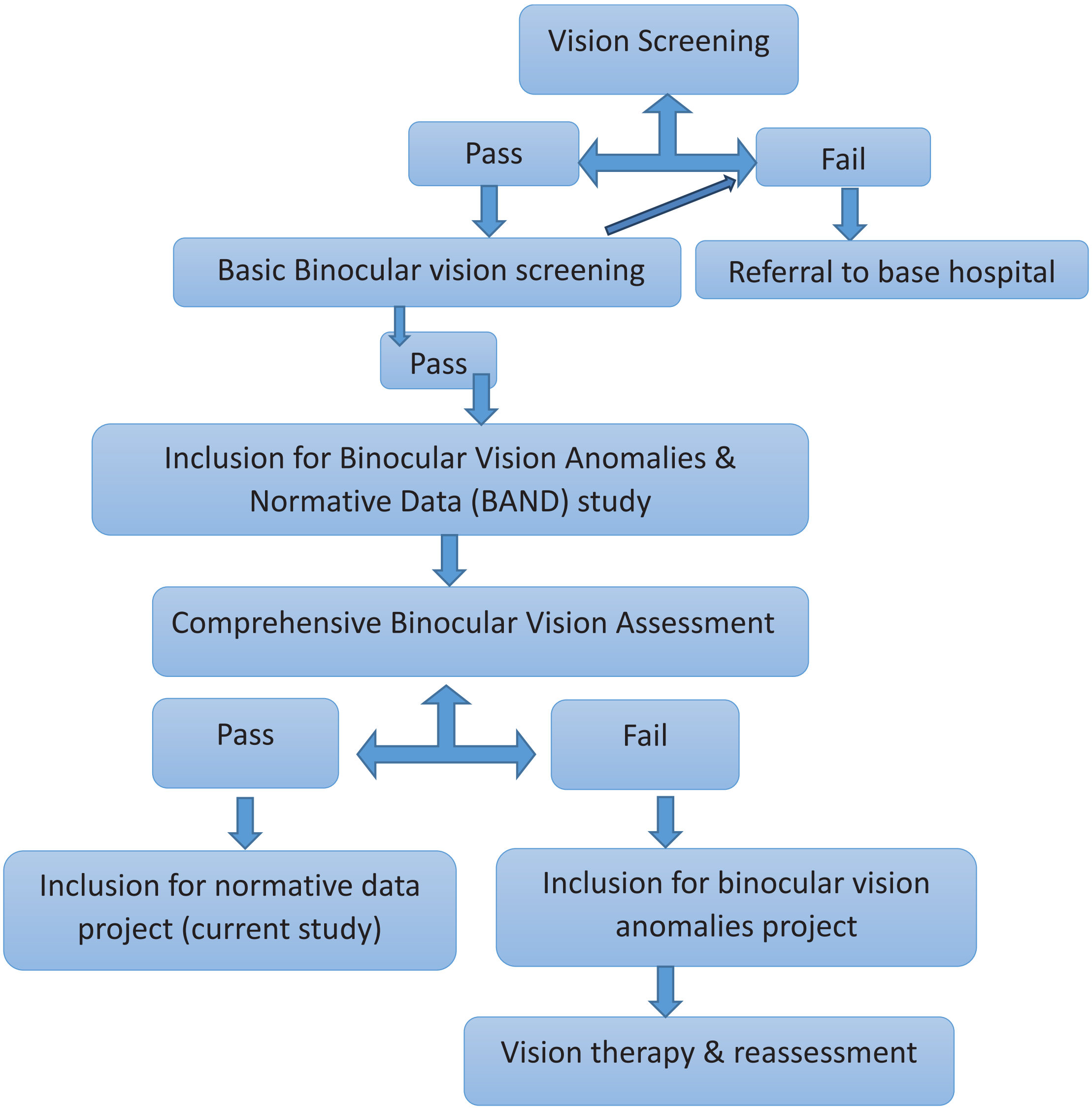

FIGURE 2.1 Flowchart depicting the recruitment of subjects for the study

2.1.4 Phase III B: Detailed Binocular Vision Assessment

The room where BV assessment was done were standardized for illumination levels (minimum of 480 Lux were ensured) and a minimum length of 6 m were chosen to perform vision tests and BV assessment for distance and near.

The outcome parameters in our study included the NPC, phoria measures for distance and near, vergence amplitudes, vergence facility, NPA, accommodative response, and accommodative facility.

2.1.4.1 Tests for vergence

Different targets for NPC testing have been reported in the literature. In our study, considering the age range to be tested, NPC was assessed using two methods 1) an Astron International rule consisting of linear accommodative target of 6/9 reduced Snellen letters and 2) using a penlight with red filter in front of right eye. The accommodative target procedure has been used extensively in the clinical set up and its reliability has been well established (Scheiman et al, 2003). Penlight with red filter is considered to be a sensitive test in diagnosing CI as it tests for the maximum fusional ability of the subject eliminating the demand for accommodative convergence (Jimenez et al., 2004; Scheiman et al., 2003; Capobianco, 2952; Pang et al, 2010). The measurements were taken from the center of the forehead as the zero reference point. The break values were noted at a point when the patient reports doubling of images while the examiner also objectively noted the deviation of one of the eyes when fusion was lost. Both the tests were repeated thrice and average of the three measurements was recorded as NPC. Both break and recovery values were noted down. NPC maintained up to the center of the forehead were given a value of 1 cm for analyses purposes.

Presence of heterophoria and the magnitude of deviation were assessed using the modified Thorington (MT) test using a Bernell muscle imbalance measure (MIM) card. The horizontal and the vertical deviations were assessed at a distances of 3 m and 40 cm. The subject was put with a trial frame with the Maddox rod oriented in the right eye horizontally and vertically for horizontal and vertical deviations respectively. The subject was asked to report the position of the red streak on the horizontal and vertical numbers and the appropriate prism deviations were noted down from the MIM card. If the red streak was reported out of the MIM card, or in case of unreliable responses, prism cover test was done to assess the magnitude of heterophoria.

The accommodative convergence/accommodation (AC/A) ratio was calculated using the expression (Rutstein & Daum, 1998) AC/A = IPD + FD* (NP-FP) where IPD in centimeters, near fixation distance (FD) in metres, and near and far phoria (NP and FP) values in prism diopters were fed into the equation. Inter-pupillary distance (IPD) was assessed using the Essilor® Pupillometer.

Fusional vergence amplitudes were assessed using step vergence technique using a prism bar as it gives the advantage of objectively rechecking the end point for vergence based on the deviation of one of the eyes during testing (Scheiman & Wick, 2014). For both near and far, the NFV was measured first followed by PFV to avoid influence of convergence testing on vergence recovery. Vertical row of letter of 6/9 Snellen equivalent was used as the test stimuli and the prisms would be gradually increased in front of one eye until the subject reports diplopia (fusional vergence break) and then the amount of prisms was reduced until binocular single vision was restored (fusional recovery). The vergence testing was done in free space without any chin rest or head support to mimic the natural testing conditions in the clinical set-up.

Apart from fusional vergence amplitudes, testing for vergence facility improves the sensitivity of diagnosis of BV anomalies and a 12 base-out/ 3 base-in prisms combination has been found to differentiate the symptomatic from the normal BV group (Gall et al, 1998). The flip prisms combination was flipped from base-in to out and the subject was asked to keep the vertical row of 6/9 letters clear and single. A practice session for 30s is provided before the test is begun. One round of base-out and base-in was counted as one cycle and the number of cycles per minute (CPM) was noted down. While the test is being done, the simultaneous vergence movement of the eyes was noted down to ensure bi-fixation. If the bi-fixation movement is not noted along with nil appreciation of diplopia during testing, suppression is indicated and was noted down.

2.1.4.2 Tests for accommodation

The NPA is the most important parameter used in the diagnosis of accommodative anomalies. With respect to the measurements techniques, push-up technique has been considered as a standard one due to its robustness, where the near target equal to or one line better than the best corrected near visual acuity is moved closer to the eyes until a sustained blur is noted. The readings in metrics were converted to diopters to arrive at the NPA. Though, this technique has problems of varying magnification of the target due to proximity, it has still been followed routinely in the clinical set-up. A modification suggested by Scheiman & Wick (2014) to overcome this limitation include decreasing the near target size as it is taken closer to the patient's eyes. Because of the simplicity of administration and its use in the clinical set-up, the push-up technique was adopted for the study.

The near point card with 6/6 Snellen equivalent word was used as the target and was brought closer to the right eye until the subject reports sustained blur. The Astron International rule centered on the forehead was used to measure the endpoint of blur. The test was repeated binocularly; two measurements were taken for both eyes and the average of the two readings was noted down in centimeters and then converted to its dioptric equivalent.

Accommodative response refers to the response of the visual system to an accommodative stimulus and the difference between the stimulus and response is termed as lag or lead of accommodation. Physiologically, the response is less than the stimulus which is a purposeful error as a result of the depth of focus and steady state accommodation properties of the eye (Rutstein et al, 1993), and the numerical value of the response is on the positive side defined as the lag of accommodation. If the response equals the stimulus, the numerical value of the response is zero; and if the accommodative response exceeds the stimulus, the numerical value is on the negative side defined as lead of accommodation. There are different techniques to estimate the accommodative response that include manual techniques such as monocular estimate method (MEM) retinoscopy, Nott retinoscopy, and automated techniques such as using open field autorefractor and power refractor. MEM and Nott retinoscopy findings were comparable and less variable than the autorefractor accommodative responses (Manny et al, 2009). MEM retinoscopy is widely practiced in the clinical setup as a result of its simplicity and ease to correlate with clinical findings.

The MEM retinoscopy was performed on the right eye of all the subjects by quickly scanning across the horizontal meridian while the subject read the grade appropriate near reading material pasted on the retinoscope. As the child read the words aloud, appropriate lens powers were quickly interposed until neutrality is observed. The lens powers used were recorded accordingly.

Accommodative facility testing is gaining increasing evidence as a representation of dynamics of the accommodative system. Plus and minus lenses of equal magnitude were interposed in front of the eyes and the visual system's response to relax and stimulate accommodation respectively were assessed. Reading material (standard practice is use of a word rock card consisting of letters of N10 and N8 font size) was used and the subject was asked to focus, keep the words clear and then read them as quickly as possible through plus and minus lenses alternately. The number of words read in one minute was noted down and the accommodative facility was calculated in CPM where one cycle represents focusing through a plus and minus lens (accounting to two words for one cycle). Using plus or minus symbol 2.00 DS lenses at 40 cm is recommended for children to differentiate between symptomatic and symptomatic individuals (Scheiman et al, 2014) and use of amplitude scaled facility and suppression check was recommended as a standard testing approach in adults (Wick et al., 2002; Yothers et al, 2002). In our study, 20/40 font size for 7–10 years and 20/30 font size for greater than 10 years were utilized and the letters were chosen from their grade text books to ensure that language difficulty does not influence the test results. Forty three-letter words were chosen and the word rock grid has been made. While the procedure was done, the subject was given a practice session for 30 s before beginning the test to ensure familiarity of the task and to minimize learning effect. Monocular accommodative facility was assessed in the right eye for all the subjects followed by binocular accommodative facility. In the pilot study before methodology was decided, binocular accommodative facility was tested using the Bernell No.9 vectogram using a polaroid glasses as suppression check. This target was found to be difficult to comprehend in our sample and therefore, the word rock card was utilized for binocular testing in this study. If suppression was revealed in other testing, then the binocular accommodative facility will not be performed and was noted down as suppression.

2.1.4.3 Repetition of tests

NPC was done thrice, NPA and vergence amplitudes were measured twice (Scheiman & Wick, 2014; Scheiman et al., 2005), MEM lag once and the accommodative and vergence facility were measured once (after a practice session for 30 s) and the average is taken for analyses.

2.1.5 Phase III C: Vision-related Quality of Life Assessment

The convergence insufficiency symptom survey (CISS) questionnaire (Borsting et al, 2009) was used to assess the severity of visual symptoms (15 items scored between 0 and 48 with greater scores indicating increasing symptoms associated with reading). The academic performance of each child would be obtained from their academic records and the academic behavior survey (ABS) designed by Rouse et al (2009) was administered to the respective class teachers to score the child on their academic performance. This is done to understand the impact of NSBVA on academic performance of children. It is agreed that the ABS is designed to be administered to parent, as parents have better awareness about academic performance of the child. But in a population-based study like this, sending questionnaire to home to be filled by the parent poses difficulty to track and get the questionnaire back. Therefore, the questionnaire was administered to the class teacher at the school set-up on the same day of screening.

2.1.6 Phase III D and E: Diagnosis of Non-strabismic Binocular Vision Anomalies (NSBVA)

The normative data obtained from the study was used to provide cut-off for the generic criteria adopted for the classification of NSBVA. This generic criteria (Scheiman & Wick, 2014) adopted for the diagnosis of NSBVA include conditions of CI, convergence excess, divergence insufficiency, divergence excess, basic esophoria, basic exophoria, AI, accommodative excess, accommodative infacility, and fusional vergence dysfunction. The prevalence of each specific type of NSBVA was calculated. The cut-off for the generic criteria was formulated after the normative data collection was over. Mean $\pm$1.00 SD was used as the cut-off for the BV parameters.

Once a child was diagnosed with a NSBVA, appropriate vision therapy protocol (Scheiman et al., 2005, 2008; Scheiman & Wick, 2014) was administered at the school. Vision therapy set-up was planned at the school premises itself to improve compliance and to prevent loss of follow-up. A reassessment of BV parameters was carried at the end of 10 sessions of vision therapy. Comparison of BV parameters before and after vision therapy was analyzed.

2.1.7 Phase IV: ROC analysis and reassessment of prevalence with the minimum test battery

After the prevalence estimates were over, the ROC analyses was performed to understand the minimum test battery needed to diagnose BV anomalies in a community set up. Receiver operating characteristic (ROC) analyses are employed to find the sensitivity and specificity of specific parameters or clinical tests. Based on the cut-off points of the tests that provide the best combination of specificity and sensitivity, the tests are chosen or recommended for screening (Florkowski, 2008). After the ROC analyses, reassessment of prevalence was carried out on a cohort of subjects in one school. The prevalence estimates obtained from this phase were compared with the earlier obtained prevalence to validate the minimum test battery.

2.2 PILOT STUDY TO DETERMINE THE SAMPLE SIZE

Since there were no available data on prevalence of BV anomalies in India, a pilot study was conducted on 100 children (age between 15 and 18 years) in the urban location. The methodology for the pilot study was the same as the main study methodology detailed in section below. The criteria and cut-off for the criteria for diagnosis of NSBVA was adopted from Scheiman & Wick (2014). From the pilot study, the prevalence of symptomatic NSBVA was found to be 46%. Based on this estimate, the sample size was estimated to be 780 at 95% confidence interval and 5% precision with a design effect of 2 for cluster sampling. Considering a 20% loss to follow-up with the intervention arm, the calculated sample size was 936. Before the actual study began, another pilot study was carried out on 31 children in two schools for the learning curve of examiners and to understand the any constraints with testing. For example, modifications in methodology of stereopsis and accommodative facility were made based on the understanding and literacy levels of the children.

2.3 PRELIMINARY RESULTS

The prevalence of NSBVA in the pilot study (n = 100) was 46%. The classification of categories of NSBVA is listed in Table 2.3. The most prevalent NSBVA was CI (32% in the overall population and 69.5% among the NSBVA) followed by accommodative infacility (10% in the overall population 21.7% among the NSBVA).

TABLE 2.3 Prevalence of NSBVA – the pilot results

Category	N
Normal BV	54
NSBVA	46
Convergence Insufficiency	32
Convergence excess	3
Divergence excess	1
Accommodative infacility	10

2.4 DATA MANAGEMENT

Descriptive statistics was calculated for all of the BV and accommodative tests in the different age groups. Intra-class correlation coefficient was used to determine the inter-examiner reliability for BV parameters carried out by three different examiners. One-way ANOVA and linear regression was utilized to assess the developmental trend of the parameters among the various age groups. The normative data for the population were estimated from the sample using the mean and standard deviation of the measured parameters. The values of the accommodation and BV parameters were rounded to the closest integer.

Descriptive statistics of proportions was calculated for all the BV anomalies and differences in proportions were analyzed between the rural and urban population. Similarly, difference in prevalence trends between the gender and age groups were analyzed. Statistical comparisons were made using Z-test for proportions with the *p*-value cut-off of 0.05 for statistical significance.

ROC curves were plotted to estimate the sensitivity and specificity for single test and combination of tests, with different cut-off points derived from the normative data. The ROC curve that has an area close to 1 is chosen as the best, and the test is considered more accurate. Based on the ROC results, the prevalence of NSBVA was calculated as proportion in a new set of 305 children. Z-test was used to compare the new proportion with the proportion calculated from the first phase based on the comprehensive BV assessment. The precision error for prevalence difference was set at 5% (Arya et al, 2012).

Descriptive statistics (Mean and SD) were calculated for BV parameters pre- and post-VT. Paired *t*-test was used to analyze the changed with 95% confidence interval for difference in mean. The proportion of yes and no to the closed-ended questions were calculated. $p < 0.0.5$ was used as the cut-off for statistical significance.

Descriptive statistics were calculated for the scores of CISS and ABS in the overall sample and children with NSBVA and NBV. Median and interquartile range (IQR) was utilized for descriptive statistics due to the ordinal rank of the data. Similarly, median and IQR was calculated for the percentage score obtained from the academic achievement report. Spearman's rank correlation was used to correlate CISS, academic performance scores and ABS scores and chi-square statistic was used to find association between academic performance, CISS and ABS. p-value <0.05 was used as the cut-off for statistical significance.

CHAPTER 3

NORMATIVE DATA OF BINOCULAR VISION PARAMETERS AMONG SCHOOL CHILDREN IN TAMILNADU

ABSTRACT

Purpose: This population-based, cross-sectional study was designed to determine normative data for binocular vision (BV) parameters and accommodation parameters in rural and urban populations of Tamilnadu.

Methods: A sample of 936 was determined based on a previous pilot study. The epidemiological field work included a comprehensive eye examination, and a BV and accommodative assessment carried out in a total of four public schools, two each in the rural and urban arms of Chennai. An overall sample of 3024 children between 7 and 17 years of age were screened in the four schools and 920 children were included in the study.

Results: We found clinically significant differences in expected values for near point of convergence (NPC) with penlight (PL), distance and near horizontal phoria, vergence facility, accommodative convergence/accommodation (AC/A) ratio, accommodative amplitudes (AA), monocular and binocular accommodative facility. The mean (SD) values for vergence (NPC, positive (PFV) and negative fusional vergence (NFV), vergence facility, phoria, and AC/A ratio) and accommodation (accommodative amplitudes, accommodative response, and accommodative facility) testing are reported. The mean (SD) break/recovery values for NPC (in cm) with accommodative target (AT) and penlight with red filter was 3(3)/4(4) and 7(5)/10(7) respectively. The break/recovery values for fusional vergence amplitudes (in prism diopters) are as follows: distance PFV: 17(8)/12(7), near PFV: 26(10)/21(10), distance NFV: 8(2)/6(2), near NFV: 15(4)/11(4). The mean accommodative amplitudes for the population could be estimated from the linear regression equation 16-0.3*(age). The vergence facility was 12(4) cycles per minutes (CPM) and 14(4) CPM in the 7–10 and 11–17 age groups respectively. Monocular accommodative facility was 11(4) CPM and 14(5) CPM and binocular accommodative facility was 10(4) CPM and 14(5) CPM in the 7–12 and 13–17 age groups respectively. The mean accommodative response was +0.4(0.2) diopters. Mean phoria values (in prism diopters) were as follows: distance: horizontal: 0.02(1) vertical: 0(0.5); near: horizontal: –0.4(2) vertical: 0 (0.5). The mean (SD) stereopsis was 40(15) arc seconds and the mean (SD) AC/A ratio was 5.4(0.6).

Conclusion: The normative data for vergence and accommodative parameters for the Indian children between 7 and 17 years of age are reported. The developmental trend of accommodation and vergence differences and significant differences in cut-off between the current data and available literature are reported.

Key Words: Normative Data, Binocular Vision, Convergence, Accommodation, School Screening

3.1 INTRODUCTION

Other than refractive anomalies, accommodative and binocular vision (BV) problems are the most common vision disorders in the clinical pediatric population (Scheiman et al., 1996; Rouse et al, 1998). These dysfunctions are termed under a broad umbrella "non-strabismic binocular vision anomalies" (NSBVA), and the expected findings or normative data for BV and accommodative testing used for the diagnosis and classification of NSBVA vary by ethnicity (Chen & Iqbal., 2000; Rambo., 1957; Rambo & Sangal, 1960). The most commonly used criteria are those reported by Morgan (1944) and Scheiman and Wick (2014). One problem with these published norms is that they were developed primarily using adult subjects. In Morgan's (1944) study, he states that "the clinical data of some 800 subjects was analyzed by statistical methods". It does not state the ages of the subject or even provide a mean age. Later in the paper, he states that all subjects had amplitude of accommodation of at least 5 D, and thus, the sample could be assumed primarily as an adult population.

These issues suggest the need for a population based study of the pediatric population in India to evaluate whether commonly used normative data established in the USA are applicable to children in India. The binocular vision anomalies and normative data (BAND) study is designed to determine the expected values for BV and accommodative testing in school children in rural and urban Tamilnadu.

3.2 METHODS

Full details of the BAND project methodology have been provided in chapter 2. The detailed procedures for all the BV tests are described in a previous publication (Hussaindeen et al, 2015).

3.3 RESULTS

The mean age of the sample was 13.2 (SD: 2.3) and 11.6 (SD: 2.9) years in the rural and urban arms, respectively. Forty-eight percentage of the subjects were female in the rural sample, and forty-two percentage in the urban population. The intra-class correlation (ICC) (95% CI) for the BV parameters are provided in Table 3.1. The reliability measures were within clinically acceptable ranges (Scheiman & Wick., 2014; Antona et al., 2008; Rouse et al, 2002).

TABLE 3.1 Intraclass correlation (ICC) coefficient for binocular vision parameters

Binocular Vision/Accommodative Test	ICC (95% CI)
Monocular AA	0.8 (0.72–0.9)
Binocular AA	0.8 (0.7–0.9)
Accommodation lag [monocular estimate method (MEM)]	0.9 (0.8–0.93)
NPC break with AT	0.8 (0.77–0.94)
NPC recovery with AT	0.74 (0.7–0.92)
NPC break with PL	0.7 (0.66–0.88)
NPC recovery with PL	0.7 (0.6–0.8)
Distance PFV break	0.72 (0.7–0.88)
Distance PFV recovery	0.8 (0.7–0.91)
Distance NFV break	0.8 (0.72–0.9)
Distance NFV recovery	0.8 (0.77–0.91)
Near PFV break	0.76 (0.7–088)
Near PFV recovery	0.77 (0.7–0.91)
Near NFV break	0.8 (0.6–0.9)
Near NFV recovery	0.72 (0.6–0.9)

There was no statistical significance for accommodation and vergence parameters, except accommodative facility (unpaired *t*-test – $p < 0.05$), between the rural and urban population (Table 3.2). Hence the normative values were estimated by combining the rural and urban population data (n = 637).

TABLE 3.2 Binocular vision and accommodation parameters in the rural and urban population

Accommodation Parameters	**Urban (N = 252)**	**Rural (N = 385)**
Monocular AA (in dioptres)	12.2 (3.2)	11 (2)
Binocular AA (in dioptres)	12.7 (3.2)	11 (3)
Monocular accommodative facility (in CPM)	14 (5)	11 (4.5)
Binocular accommodative facility (in CPM)	14 (5)	11 (4.2)
Accommodation lag (in diopters)	0.4 (0.2)	0.3 (0.2)
Vergence parameters		
Vergence facility (in CPM)	12 (4)	12 (4)
NPC with AT break (in cm)	3.2 (2.8)	2.5 (2.3)
NPC with AT recovery (in cm)	4.1 (3.8)	3.3 (3.5)
NPC with PL break (in cm)	6.8 (5.3)	6.8 (5.3)
NPC with PL recovery (in cm)	9.6 (7)	9.9 (7.3)
Near PFV break (in prism dioptres)	27 (10)	26 (10)
Near PFV recovery (in prism dioptres)	22 (10)	20 (9)
Near NFV break (in prism dioptres)	14 (4)	15 (4)
Near NFV recovery (in prism dioptres)	11 (4)	12 (4)
Distance PFV break (in prism dioptres)	19 (8)	16 (7)
Distance PFV recovery (in prism dioptres)	14 (8)	11 (6)
Distance NFV break (in prism dioptres)	9 (3)	8 (2)
Distance NFV recovery (in prism dioptres)	6 (2)	5 (2)
Distance horizontal phoria (in prism dioptres)	0.1 (0.7)	0 (0.8)
Near horizontal phoria (in prism dioptres)	–0.3 (1.7)	–0.5 (1.5)
Distance vertical phoria (in prism dioptres)	0 (0.1)	0 (0.3)
Near vertical phoria (in prism dioptres)	0 (0.3)	0 (0.3)
Stereopsis (in arc sec)	41 (15)	40 (16)
AC/A ratio	5.1 (0.6)	5.5 (0.6)

Results of the BV and accommodative testing were compared across the age groups of 7–17 using one-way ANOVA and post-hoc Bonferroni analyses. The developmental trend of BV parameters with age was analyzed through simple linear regression and these parameters are provided in Table 3.3. Post-hoc Bonferroni analysis with the conservative *p*-value (0.004) revealed significant differences for all the accommodative tests (accommodative amplitudes, facility, and lag) and for two BV tests (near NFV recovery and vergence facility). We also looked for significant correlations with various age groups, in the post-hoc analysis in the statistically significant groups and these are reported in Table 3.3.

As a result of differing visual demands between lower and higher grades at school and existing evidence in literature that these groups may be different in regard to BV and accommodative function (Hayes et al, 1998) the sample was analyzed using two age groups (7–12 and 13–17 years old). The distribution of subjects with normal BV in the two age groups of 7–12 and 13–17 years is presented in Table 3.4. Statistically significant differences were found between the two age groups for accommodative testing (accommodative

TABLE 3.3 Developmental trend of binocular vision parameters

Binocular Vision/Accommodative Test	ANOVA p-value	R^2 Value	Age Trend
Monocular AA	<0.001	0.79	7–10, 11–17
Binocular AA	<0.001	0.8	7–10, 11–17
Monocular accommodative facility	<0.001	0.5	7–11, 12–17
Binocular accommodative facility	<0.001	0.35	7–11, 12–17
Accommodation lag (MEM)	<0.001	0.01	7–12, 13–17
NPC break with AT	0.001	0.015	Not found
NPC recovery with AT	<0.001	0.013	Not found
Distance PFV break	0.003	0.02	Not found
Near NFV break	<0.001	0.67	Not found
Near NFV recovery	<0.001	0.82	7–12, 13–17
Near horizontal phoria	0.02	0.02	Not found
Vergence facility	<0.001	0.84	7–11, 12–17

TABLE 3.4 Normative data for the Indian population for accommodation and vergence parameters from the BAND study

Accommodation parameters	**Age Groups**	
	7–10	**11–17**
Monocular AA (in dioptres)	13 (3)	11 (2)
Binocular AA (in dioptres)	13 (3)	11 (3)
	7–12	**13–17**
Monocular accommodative facility (in CPM)	11 (4)	14 (5)
Binocular accommodative facility (in CPM)	10 (4)	14 (5)
Accommodation lag (in diopters)	+0.4 (0.2)	NA
Vergence parameters	**7–12**	**13–17**
Vergence facility (in CPM)	12 (4)	14 (4)
IPD (in mm)	55 (3.3)	59 (3)
NPC with AT break (in cm)	3 (3)	
NPC with AT recovery (in cm)	4 (4)	
NPC with PL break (in cm)	7 (5)	
NPC with PL recovery (in cm)	10 (7)	
Near PFV break (in prism dioptres)	26 (10)	
Near PFV recovery (in prism dioptres)	21 (10)	
Near NFV break (in prism dioptres)	15 (4)	
Near NFV recovery (in prism dioptres)	11 (4)	
Distance PFV break (in prism dioptres)	17 (8)	
Distance PFV recovery (in prism dioptres)	12 (7)	
Distance NFV break (in prism dioptres)	8 (2)	
Distance NFV recovery (in prism dioptres)	6 (2)	
Distance horizontal phoria (in prism dioptres)	0.02 (1)	
Near horizontal phoria (in prism dioptres)	–0.4 (2)	
Distance vertical phoria (in prism dioptres)	0 (0.5)	
Near vertical phoria (in prism dioptres)	0 (0.5)	
Stereopsis (in arc sec)	40 (15)	
AC/A ratio	5.4 (0.6)	

facility and lag) and BV testing (NPC with AT, vergence facility, near NFV (break and recovery), distance PFV, NFV (break and recovery), near horizontal phoria. The data for accommodative amplitudes is provided in Table 3.5.

Linear regression analysis revealed a significant association between age and amplitude of accommodation (AA) with the linear regression equation of AA = 16 – 0.3*(age) ($R^2 = 0.8$; ANOVA $P < 0.0001$) (Figure 3.1).

We also identified 2 clusters of 7–10 years and 11–17 years in the AA trend, and therefore, a grouped mean for these 2 clusters were calculated and represented (Table 3.5). Among the 637 children, five children did not report blur while testing AA and this data was excluded from the analyses.

Based on the results, the recommended values for accommodation and vergence parameters are provided in Table 3.4. For statistically insignificant differences between the age groups, the grouped mean is provided for the data, and for significant difference in means between the age groups, separate data is provided.

TABLE 3.5 Mean amplitude of accommodation for ages

Age (N)	Mean (SD) AA	95% CI of Mean	Hofstetter's Average AA
7 (41)	13.7 (1.3)	13.3, 14.1	16.4
8 (56)	13.2 (2)	12.6, 13.7	16.1
9 (51)	13.3 (2.6)	12.6, 14	15.8
10 (54)	13.2 (3.2)	12.3, 14	15.5
11 (52)	11.3 (2.6)	10.5, 11.9	15.2
12 (79)	11.8 (2.8)	11.4, 12.6	14.9
13 (92)	11.4 (3.2)	10.7, 12	14.6
14 (52)	10 (1.6)	9.6, 10.4	14.3
15 (66)	10.8 (2.1)	10.3, 11.3	14
16–17 (89)	10.6 (1.6)	10.3, 10.9	13.7
Grouped Data			
7–10 (202)	13.3 (2.5)	13, 13.7	NA
11–17 (430)	11.1 (2.5)	10.9, 11.3	NA

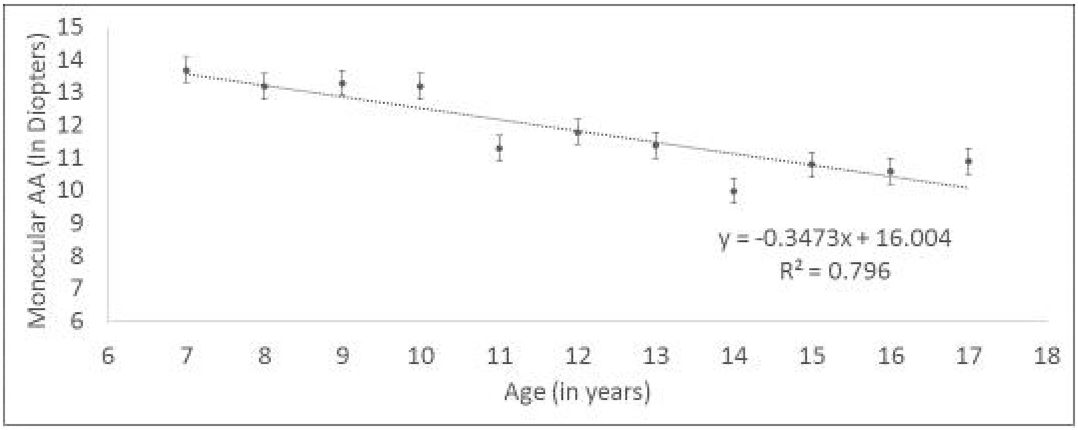

FIGURE 3.1 Age vs. amplitude of accommodation among 7–17 year old

3.4 DISCUSSION

The results of this study provide normative data for BV and accommodative testing for school children in the Indian population. NPC, horizontal phoria, vergence facility, AC/A ratio, accommodative amplitudes, and accommodative facility were found to be different in our population compared to current standards (Morgan., 1944; Scheiman & Wick, 2014; Duane, 1926).

Comparison of BV parameters obtained in our study with that of studies that have similar methodology is presented in Table 3.6 and 3.7. Statistically significant differences in cut-off values were found for a number of BV tests, and accommodative tests (Table 3.6). Fusional vergence ranges were found to be clinically comparable to previously published normative data (Table 3.7).

The present study proposes the mean (SD) cut-off NPC break of 3(3) cm and 7(5) cm using an AT and a penlight respectively. The cut-off for NPC break with an AT correlates with that of Scheiman et al (2003) & Chen et al (2000) and for penlight with that of Jimenez et al (2004). It has been reported that there is no difference between the break points obtained for NPC with AT vs. penlight among controls (Capobianco, 1952) and penlight is a more sensitive test for diagnosing convergence insufficiency (Capobianco, 1952; Pang et al, 2010). However, the results of our study shows a significant difference in NPC values between AT and penlight with red filter even among controls. This could be understood from the physiological perspective of difference in vergence response when accommodation cues are present. With AT, both fusional and accommodative vergence

TABLE 3.6 Comparison of study data to published expected values

	Study Data Mean (SD)	**Morgan (1944) & Scheiman and Wick (2014) Mean (SD)**	**p-value (one sample t-test)**
Distance phoria	0.02 esophoria (1)	1 exophoria (2)	<0.001
Near phoria	–0.4 exophoria (2)	3 exophoria (3)	<0.001
AC/A ratio	5.4:1 (0.6)	4:1 (2)	<0.001
Step vergence testing			
Base-out (near)	Break:26 (10)	Break:23 (8)	<0.001
	Recovery:21 (10)	Recovery:16 (6)	<0.001
Base-in (near)	Break:15 (4)	Break:12 (5)	<0.001
	Recovery:11 (4)	Recovery: 7 (4)	<0.001
Vergence facility testing (12 base-out/3 base-in) 7–12 year old	12 CPM (4)	15 CPM (3)	<0.001
Near point of convergence			
Accommodative target	Break:3 cm (3)	Break:2.5 cm (2.5)	0.003
	Recovery:4 cm (4)	Recovery:4.5 cm (3)	<0.001
Penlight and red/green glasses	Break: 7 cm (5)	Break:2.5 cm (4)	<0.001
	Recovery:10 cm (7)	Recovery:4.5 cm (5)	<0.001
Monocular accommodative facility			
6 year old	11 CPM (4)	5.5 CPM (2.5)	<0.001
7 year old		6.5 CPM (2)	
8–12 year old		7.0 CPM (2.5)	
13–30 year old	13 CPM (5)	11.0 CPM (5)	<0.001
Binocular accommodative facility			
6 year old	11 CPM (4)	3.0 CPM (2.5)	<0.001
7 year old		3.5 CPM (2.5)	
8–12 year old		5.0 CPM (2.5)	
Monocular estimate method retinoscopy	+0. 4 D (0.2)	+0.50 D (0.25)	<0.001

TABLE 3.7 Fusional vergence measures of the present study compared with the literature

	Author	Morgan (1944)	Scheiman et al (1989)	Jimenez et al (2004)	Antona et al (2008)	Present Study (2015)
	Sample size	800	386	1015	61	637
	Age (in years)	Pre-presbyopic adults	7–12	6–12	18–32	7–17
	Method	Phorometry	Step vergence	MT/ Step vergence	Step vergence	MT/ Step vergence
Phoria (in PD) (SD)	Distance	1 exo (2)	NA	0.6 eso (2)	NA	0.02 eso (1)
	Near	3 Exo (5)	NA	0.4 exo (3)	NA	0.4 exo (2)
Vergence values (Blur/ break/ recovery)	Distance NFV	x/ 7(3)/ 4(2)	NA	x/ 6(2)/ 4(2)	X/8.63 (1.94)/ 6.26 (1.82)	x/ 8(2)/ 6(2)
	Near NFV	13 (4)/21(4)/ 13(5)	x/12(5)/ 7(4)	x/11(3)/ 7(3)	X/8.75 (3.37)/ 12.14 (3.35)	x/15(4)/ 11(4)
	Distance PFV	9 (4)/19(8)/ 10(4)	NA	x/17(7)/ 11(6)	X/ 23.25 (7.68)/ 14.5 (4.17)	x/17(8)/ 12(7)
	Near PFV	17 (5)/21(6)/ 11(7)	x/23(8)/ 16(6)	x/18(13)/ 8(6)	X/ 28.91 (9.09)/ 19.65 (5.98)	x/26(10)/ 21(10)

NA – Not available

are active, whereas with a penlight, accommodation cues are minimal, thus, reducing the overall vergence output.

The phoria ranges in this Indian population sample indicate essentially orthophoria at distance in both the 7–12 and 13–17 years age groups. At near, exophoria was found increasing in the older age group. The findings in our study are comparable to phoria data reported in the Spanish population (Jimenez et al, 2004) and indicate less exophoria compared to the expected finding proposed by Morgan et al (1944). This difference could be potentially attributed to the difference in methodology and the tests used for phoria measurement (Casillas et al., 2002; Sanker et al., 2012; Schroeder et al., 1996; Rainey et al, 1998). The trend for the fusional vergence ranges in the present study is comparable with that of the existing normative data (Jimenez et al., 2004; Antona et al., 2008; Scheiman et al., 1989; Scobee & Green, 1948).

The present study reveals a mean calculated (SD) AC/A ratio of 5.4:1 (0.6) and 5.7:1 (1.1) in the 7–12 and 13–17 years respectively. In 1972, Sen and Malik (1972), determined AC/A ratio for 100 normal subjects. The mean value was 2.28, (Range: 0.5–4.0). Women had slightly lower AC/A ratios than males, although the difference was not statistically significant. Our data suggests a higher mean calculated (SD) AC/A ratio compared to the existing Indian data (Sen & Malik, 1972) and Morgan's (1944) data but correlates with that of Jimenez et al (2004). These differences are likely due to variation of measurement technique (calculated vs. gradient). The calculated AC/A measurement gives a higher estimate of AC/A due to influence of proximal vergence and accommodation lag, whereas in gradient technique, these factors are kept constant due to measurement at fixed distance. Our study utilized the calculated method compared to gradient method in the Sen and Malik's study (1972). Another difference between the two studies is the age group. Sen and Malik's (1972) study had a wider age range of 6–61 years compared to our study with a narrower age range of 7–17 years. Data for vergence facility (Gall et al, 1998) and stereopsis (Romano et al, 1975) were comparable with the existing literature.

To the best of our knowledge, our study is the first to report amplitude of accommodation by age in Indian school children. Our equation [AA = 16- 0.3 (age)] predicts that the accommodative amplitudes are significantly lower in the Indian population by a minimum of 2.5 D compared to Hofstetter's (Donder., 19864, 1912; Hofstetter., 1944, 1950) proposed data for average amplitude of accommodation [18.5 – 0.3 (age)]. Rambo et al (1957) measured the amplitude of accommodation from 1340 eyes in the age group 10–50 years. They found that there were rapid falls in the amplitude at 15 years and 37.5 years in Indians. Among the 7–17 year age range, we noticed a dip at 10 years of age, beyond which the AA was stable up to 17 years of age. Similar lower amplitudes of accommodation, compared to Hofstetter's data have been observed by Sterner et al (2004) and a similar linear regression equation has been proposed by Chen et al (2000). In Sterner et al (2004) study of 76 children in the age range of 6–10 years, a mean difference of 3.5 D in the monocular measures of accommodation, has been observed in more than 50% of the sample. This difference in amplitude of accommodation between ethnicities suggest the need for further investigation, to study the possible role of visual demand, and other physiological factors such as lens curvature and zonular functions. We also observed better binocular amplitudes compared to monocular amplitudes which is consistent with previous literature (Chen et al., 2000; Sterner et al, 2004).

The monocular and binocular accommodative facility mean (SD) were 11 (4) CPM and 13 (5) in the age ranges of 7–12 and 13–17 respectively. These values are higher compared to the literature (Scheiman & Wick, 2014), and this may be attributed to the difference in testing. In this study, we utilized a simple grade level target for testing without a suppression check, and yielded better values than the existing expected finding. As expected, the amplitude of accommodation showed a significant developmental trend with age. Except for the accommodative amplitudes, various vergence and accommodation parameters also showed statistical significance, with significant R^2 value for parameters of accommodative facility, near NFV break and recovery and vergence facility. As the clinical relevance for other parameters are limited by the low R^2-value, it is relevant to consider the grouped mean of the two age groups of 7–12 and 13–17 as the normative reference for all the parameters.

A strength of this study is that it is a large, population-based sample. A limitation is that it was a convenience sample and we utilized cross-sectional data for comparing developmental trends of BV parameters, and future longitudinal studies are warranted.

In summary, the present study suggests differences between the existing literature and Indian data for the expected findings for the age group of 7–17 years, with clinically significant differences for NPC with penlight, phoria, vergence facility, AC/A ratio, NPA, and accommodative facility. This study, thus, provides the normative data for the Indian population between 7–17 years of age.

CHAPTER 4

PREVALENCE OF NON-STRABISMIC BINOCULAR VISION ANOMALIES AMONG SCHOOL CHILDREN IN TAMILNADU

ABSTRACT

Purpose: To report the prevalence of non-strabismic binocular vision anomalies (NSBVA) among school children in rural and urban Tamilnadu

Methods: This is a population based cross-sectional study to estimate the prevalence of NSBVA in the rural and urban population of Tamilnadu. A pilot study was done to estimate the sample size followed by epidemiological field work including comprehensive eye examination and binocular vision assessment. With an estimated sample size of 936, a total of four public schools, two each in the rural and urban arms of Chennai were selected. 3024 children between 7 and 17 years of age were screened in the four schools and 920 children were included. Estimates of normative data were done in the first phase followed by estimates of prevalence of binocular vision (BV) anomalies based on the cut-off derived from the normative data.

Results: The prevalence of NSBVA in the urban and rural arms was found to be 31.5% and 29.6% respectively. Convergence insufficiency (CI) was the most prevalent (16.5% and 17.6% in the Urban and Rural arms respectively) among all the types of NSBVA. There was no gender predilection and no statistically significant difference was observed between the rural and urban arms in the prevalence of NSBVA (Z-test, $p > 0.05$). The prevalence of NSBVA was found to be higher in the 13–17 years age group (36.2%) compared to 7–12 years (25.1%) (Z-test, $p < 0.05$).

Conclusion: NSBVA are highly prevalent among school children and the prevalence increases with age. Screening for BV anomalies should be a part of the vision screening protocol and appropriate intervention should be planned for the BV anomalies.

Key Words: Normative data, Binocular vision, Convergence, Accommodation, School screening, Nonstrabismic binocular vison anomalies, convergence insufficiency, accommodative infacility

4.1 INTRODUCTION

Accommodative and vergence dysfunctions are reported to be highly prevalent among school children with estimates of close to 30% according to recent population-based studies (Jang & Park, 2015). As these dysfunctions are latent, they are termed as NSBVA. Due to the hidden (latent) nature of NSBVA, detection without clinical tests, just based on observation as in manifest squint, is not possible. To the best of our knowledge, there exists no data in the Indian literature on the prevalence of BV anomalies so as to understand the visual morbidity due to these disorders. Among the various types of NSBVA, CI, due to its high prevalence in both clinical and community set-up, has been emphasized more in the literature. Certain hospital-based reports in India quoted varied frequencies of CI from 3.6% to 7.7%. This data is more than a decade old (Dhir., 1961; Deshpande & Ghosh, 1991).

With constant change in the near visual demands, and worldwide increase in prevalence of NSBVA (Jang & Park., 2015; Wajuhian, 2015), it becomes important to understand the current status of visual morbidity due to NSBVA among school children in the indigenous population. Hence we, the BAND (Binocular vision anomalies and normative data) study group aimed to study the prevalence of BV anomalies among school children in rural and urban Tamilnadu. Estimates of BV anomalies among school children would help in planning appropriate intervention so that the visual morbidity of the disease could be reduced and vision-related quality of life could be improved in these individuals.

4.2 METHODOLOGY

The methods are detailed in chapter 2.

4.3 RESULTS

3024 children between 7 and 17 years of age were screened in four schools, and 921 children were included for the study. The mean (SD) age of the sample was 13.2 (2.3) and 11.6 (2.9) years in the rural and urban arms respectively. The prevalence of refractive errors and ocular diseases are provided in Table 4.1.

The demographic details and the distribution of BV anomalies are represented in Table 4.2. There was no significant difference in the prevalence between rural and urban population for the overall NSBVA prevalence and for the subtypes ($p > 0.05$, Z-test).

Convergence insufficiency was the highly prevalent symptomatic NSBVA in both the rural and urban population followed by AIF (Table 4.2). The proportion of NSBVA was not statistically significant between the rural and urban population and hence for age based analyses, the rural and urban data was clubbed together. Two age groups of 7–12 and 13–17 were identified based on the previous analyses from normative data of the same population (Hussaindeen et al, 2016a).

TABLE 4.1 Prevalence of refractive errors and other ocular diseases

	Rural N = 1435	**Urban** N = 1589
Refractive errors		
Myopia	28 (1.95%)	34 (2.1%)
Hyperopia	4 (0.3%)	8 (0.5%)
Astigmatism	18 (1.25%)	37 (2.3%)
Squint & amblyopia	7	2
Other ocular diseases (list below)	16 (1.1%)	21 (1.3%)
Cataract	2	5
Nystagmus	1	5
Retinal pathologies	4	5
Congenital colour blindness	4	0
Ptosis	1	4
Corneal disorders	1	2
Iris coloboma	1	0
Third nerve palsy	2	0

TABLE 4.2 Prevalence of NSBVA in the rural and urban population

	Rural N = 358	**Urban N = 562**
Mean (SD) age	13.2 (2.3)	11.6 (2.9)
Male: Female	185:173	324:238
Normal binocular vision	252 (70.4%)	385 (68.5%)
Overall NSBVA	**106 (29.6%)**	**177 (31.5%)**
Convergence insufficiency (CI)	**63 (17.6%)**	**93 (16.5%)**
Convergence excess (CE)	6 (0.8%)	10 (1.4%)
Divergence excess (DE)	0	2 (0.4%)
Fusional vergence dysfunction (FVD)	3 (0.8%)	5 (1.3%)
Divergence insufficiency (DI)	1	0
Basic esophoria (BES)	1 (0.3%)	0
Basic exophoria (BEX)	0	0
Vergence infacility	0	2
Accommodative infacility (AIF)	**29 (7%)**	**64 (10.7%)**
Accommodative excess (AE)	3 (0.8%)	0
Accommodative insufficiency (AI)	0	1 (0.2%)

Also other than CI and IAF, other subtypes of NSBVA showed prevalence close to 1% and hence statistical analysis was restricted to CI and AIF, due to adequate sample size. Age-based analyses of NSBVA prevalence revealed significant increase in prevalence in the 13–17 years age group, and these results were statistically significant (Z-test, $p < 0.0001$). Similarly, statistically significant differences were observed for the subtypes of CI and AIF (Z-test, $p < 0.0001$) (Table 4.3).

As CI was the most prevalent NSBVA among all the subtypes, followed by AIF, the mean values of BV parameters in subjects with CI and AIF is given in Table 4.4. These parameters were compared with the data of normal binocular vision (NBV) group, from the same population (Hussaindeen et al, 2016a). All the BV parameters were signifi-

TABLE 4.3 Prevalence of NSBVA in the 7–12 and 13–17 years age group in the overall population

Details of Binocular vision (BV) anomalies	7-12 Years N (%)	13-17 Years N (%)
Total Sample	**450**	**470**
Normal BV	337 (74.8)	300 (65.2)
Overall NSBVA	113 (25.1)	170 (37.2)
Convergence insufficiency (CI)	66 (14.6)	90 (19.6)
Accommodative infacility (AIF)	42 (9.3)	51 (11.1)

cantly difference between the CI and NBV group except for monocular estimate method (MEM), near vertical muscle imbalance measure (MIM), near and distance negative fusional vergence (NFV) (unpaired *t*-test; $p < 0.0001$).

As a high prevalence of AI is reported a co-morbid condition in CI (Scheiman et al., 2011; Marran et al, 2006), we analyzed the amplitude of accommodation (AA) in CI with the NBV group, and the difference in AA was found to be statistically significant (un-paired *t*-test, $p < 0.001$), but these results were clinically insignificant (mean difference (95% CI) between the two groups: 1.3 D (0.7–1.9)) (Table 4.5). In the AIF group, monocular and binocular accommodative facility, and NPC with penlight/red filter break and recovery values were significantly different from the NBV group (unpaired *t*-test; NPC–PLR $p < 0.05$; AF– monocular and binocular $p < 0.0001$).

As detailed in the methodology, subjects who failed the screening criteria were referred for further management and subjects who passed the screening criteria were included in the study. Subjects who passed the comprehensive BV assessment were included in the normative project, and those who reported visual symptoms and identified as having BV or accommodative disorders based on the BV assessment were considered to have a BV anomaly. There were subjects who had an asymptomatic BV anomaly, and others that were symptomatic but had normal BV. These combinations were analyzed and data from these subjects were reassessed prior to classifying them to one of the two groups of normal BV vs. NSBVA. Seventy-three (7.9%) children were found that fell into one of

TABLE 4.4 Mean values of BV parameters in CI and AIF subjects

BV Parameters		N = 156	N = 93
Mean age (in years)		**12.7 (2.7)**	**12.6 (2.6)**
NPC–AT (in cm)	Break	7.4 (5.2)	3.5 (3.8)
	Rec	9.5 (7.3)	4.3 (4.7)
NPC–PLR (in cm)	Break	18.4 (10.8)	9 (8)
	Rec	23.5 (11.8)	12.1 (10.3)
NPA (in cm)	M/O	10.3 (3.2)	9.3 (2.0)
	B/O	10 (3.2)	8.8 (2.1)
AA (in D)	M/O	10.5 (2.8)	11.4 (3)
	B/O	11 (3.3)	12 (3)
Near PFV (in PD)	Break	16.6 (7.6)	23.6 (10.4)
	Rec	12.8 (6.3)	17.7 (8)
Near NFV (in PD)	Break	13.9 (4)	14 (4.8)
	Rec	11 (3.9)	10.5 (4.2)
Distance PFV (in PD)	Break	12.1 (6)	15.2 (5.8)
	Rec	8.4 (5.2)	11 (4.8)
Distance NFV (in PD)	Break	7.6 (2.8)	8.3 (2.3)
	Rec	5 (2.1)	5.8 (2)
AF (in CPM)	M/O	9.5 (5.6)	4 (2)
	B/O	9.8 (5.4)	5.3 (2.7)
VF (in CPM)		8.2 (5.4)	11 (4.5)
MIM horizontal (in PD)	Dist	–0.9 (2.1)	0 (0.8)
	Near	–4.5 (3.9)	-0.1 (1.8)
MIM vertical (in PD)	Dist	0 (0.3)	0.02 (0.4)
	Near	0.1 (0.7)	0.02 (0.4)
MEM (in D)		0.3 (0.2)	0.3 (0.2)
AC/A		4.5 (1)	5.8 (0.6)

NPC–AT – Near point of convergence with accommodative target; NPC–PL – Near point of convergence with pen light and red filter; NPA – Near point of accommodation; NFV – negative fusional vergence; PFV – Positive fusional vergence; MIM – Muscle imbalance measure; MEM–Monocular estimate method; AF – Accommodative facility; VF – Vergence facility; CPM – Cycles per minute

TABLE 4.5 Monocular amplitude of accommodation (AA) in CI and NBV

	NBV (N = 637)	CI (156)
Mean (SD) AA (in diopters)	11.8 (3.1)	10.5 (2.9)
CI for mean difference	0.7–1.9	

TABLE 4.6 Symptomatic vs. asymptomatic NSBVA

		Normal	
	NSBVA	BV	Total
Symptomatic	225	15	240
Asymptomatic	58	622	680
Total	283	637	920

these two groups. Fifty-eight (6.3%) were asymptomatic, but still failed the BV tests, and were classified as having a NSBVA. Fifteen (1.6%) were symptomatic, but had normal BV parameters and were classified as normal BV (Table 4.6).

4.4 DISCUSSION

Our study is the first to report prevalence of NSBVA in the rural and urban population in southern India. This study reports a much higher prevalence of 31.5% and 29.6% in the rural and urban population respectively. CI was the most prevalent (16.5% and 17.6% in the urban and rural arms respectively) among all the types of NSBVA. Caucasian prevalence of NSBVA have been reported to be as high as 56.2% in the general adult population between 18–38 years (Montes-Mico, 2001), and 15.3% among University students (Porcar et al., 1997). In India, the prevalence of CI as reported in literature varies between 3.6% and 7.7% in the hospital-based population (Dhir., 1961; Deshpande & Ghosh, 1991). The prevalence of other types of NSBVA in Indian ethnicity are not known to the best of our knowledge. Similar to our study results, CI has been reported to be the commonest of all NSBVA in many studies, but there is a wide range of prevalence between 2.25–33% (Cacho-Martinez et al, 2010) and this difference is attributed to the diagnostic cut-off and criteria used. Most of the recent studies use a combination of parameters than a single parameter like NPC and report a similar prevalence to our study in other ethnicities (Jang & Park., 2015; Wajuhian, 2015). We adopted the standard criteria given by Scheiman et al (2014) to diagnose the BV anomalies, and instead of universally used Morgan's cut-of (1944) we used cut-off points derived from the normative data from our ethnicity (Hussaindeen et al, 2016a).

We found an increasing trend of NSBVA in the 13–17 years age group (36.2%) compared to the 7–12 years (25.1%) and this could be justified due to the increasing near visual demands. In an adult population above 19 years of age, 1 in 6 adults was diagnosed with CI (Ghadban et al, 2015) and a significant increase in exophoria by 7 PD was seen by 20 years in one fourth of the sample after the initial diagnosis. Also, significant association between reading and NSBVA have been reported in the literature (Palomo-Alvarez et al, 2008, 2010). Thus, it becomes important to understand the impact of NSBVA on reading and academic performance, and this data is represented in chapter 9.

Followed by CI (14.6% and 19.6% in the 7–12 and 13–17 years age group), AIF was the highly prevalent (9.3% and 11.1% in the 7–12 and 13–17 years age group) NSBVA. Rest of the subtypes were lesser than 2% in prevalence. The difference in prevalence that could have been observed with the existing cut-off and the BAND cut-off is illustrated in Table 4.7.

Based on the diagnostic criteria and cut-off points proposed by Scheiman et al. (2014), the prevalence estimates for CI and AIF reduced to 6% in the current sample. This suggests that an indigenous cut-off is more appropriate to detect symptomatic NSBVA. Scheiman et al (2014) used a three sign cut-off to diagnose CI. We included symptomatic subjects with two positive signs as well and this could be one reason for

TABLE 4.7 Prevalence of CI, AI, and AIF with Scheiman et al.'s (2014) cut-off and BAND cut-off (2016a)

	BAND Study (2016 a)	**Scheiman et al (2014)**
CI (%)	16	6
AI (%)	0.2	8
AIF (%)	10.1	6

the high prevalence of CI. Similarly, for the diagnosis of AIF, Scheiman et al (2014) used a cut-off of 3 CPM compared to a cut-off of 7 CPM in our study. This could explain the difference in the prevalence data. But, it is interesting to note that the prevalence of AI is 0.2% in our population, much lesser than to what is reported in the existing literature (Jang & Park., 2015; Wajuhian, 2015; Paniccia & Ayala, 2015; Scheiman et al., 2011; Marran et al, 2006; Garcia et al, 2002). One of the main reason for this finding is the indigenous cut-off for AA used in our population. If the cut-off had been based on conventional Hofstetter's (1944, 1950) minimum expected AA, 77 (8%) out of the overall 920, would have been diagnosed with AI. We also did not find children who reported symptoms of near vision blur, a finding consistent with diagnosis of AI. Similar findings of difference in AA from Hofstetter's data has been reported earlier in adult population in India (Rambo, 1957) and also by Sterner et al (2004). It is also important to note that the mean amplitudes of accommodation in CI was statistically significant from the normal BV group, though these differences were clinically insignificant.

It is important to note that a large proportion of children (20.5%) were asymptomatic in the presence of abnormal BV parameters. Literature suggests that symptomatic individuals are more likely to fail the Sheard's criterion (Sheard., 1930; Sheedy & Saladin, 1983). In our population, in the asymptomatic NSBVA group, 7 out of the 58 children failed the Sheard's criterion, whereas in the symptomatic NSBVA group, 31 out of 225 failed the Sheard's criterion. These proportions were not statistically significant (Z-test; $p > 0.05$) thus, revealing no significant association between Sheard's criterion and symptoms. Increased variability and reduced reliability associated with vergence testing could be one reason for this finding (Scheiman & Wick, 2014).

We also re-applied the standard clinical criteria for diagnosis proposed by Scheiman & Wick (2014) to the asymptomatic NSBVA group. When this criteria was applied, the proportion of asymptomatic NSBVA reduced to 14.8%. Out of the 58 children, 37 had CI, 15 had AIF, 2 had CE, and 4 had FVD. This suggests that the criteria for diagnosis does not change the proportion of asymptomatic NSBVA significantly and hence brings in dilemma from both diagnosis and management perspective. We have not done intervention for the asymptomatic NSBVA in this study, though we educated the child about the potential visual issues that could develop over a period of time. Also, there is no clarity on why these children are asymptomatic, though, reduced visual demands, cognition, and awareness could be hypothesized as possible reasons.

The higher prevalence of NSBVA reported in our study has implications for the public health strategies adopted with respect to eye care among school children. CI is the most common followed by AIF in both the rural and urban population. Screening for BV anomalies should be part of the vision screening protocol and appropriate intervention should be planned for the BV anomalies.

CHAPTER 5

THE MINIMUM TEST BATTERY TO SCREEN FOR BINOCULAR VISION ANOMALIES IN A COMMUNITY SET UP

ABSTRACT

Purpose: Binocular vision (BV) assessment in a clinical set-up is comprehensive and time consuming. The same may not be applied to a community set-up when large numbers are to be screened. Hence, this study aims to report the minimum test battery needed to screen non-strabismic binocular vision anomalies (NSBVA) in a community set-up.

Methods: The prevalence estimates and normative data for binocular vision parameters were estimated from the phase one of the BAND study, following which cut-off estimates and receiver operating characteristic (ROC) curves to identify the minimum test battery have been plotted. In the phase two, children between 9 and 17 years of age were screened in two schools in the rural arm using the minimum test battery, and the prevalence estimates with the minimum test battery was found.

Results: ROC analyses revealed that near point of convergence with penlight and red filter (NPC-PL) (>10 cm), monocular accommodative facility (MAF) (<10 CPM), and the difference between near and distance phoria (>1.25 PD) were significant factors with cut-off values for best sensitivity and specificity. In phase 2, 305 children were included and the mean (SD) age of the subjects was 12.7 (2) years with 121 male and 184 female. Using the minimum battery of tests obtained through the ROC analyses, the prevalence of NSBVA was found to be 34%. NPC with penlight with a cut-off of >10 cm was found to have the highest sensitivity (80%) and specificity (73%) for the diagnosis of CI. For the diagnosis of AIF, monocular AIF, with a cut-off of > 7 CPM was the best predictor for screening (92% sensitivity and 90% specificity).

Conclusion: The minimum test battery of difference between distance and near phoria, MAF and NPC-PL yield good sensitivity and specificity for diagnosis of NSBVA in a community set-up.

Key Words: convergence insufficiency; accommodative infacility; school vision screening; binocular vision; non-strabismic binocular vision anomalies

5.1 INTRODUCTION

Recent population-based studies across the world provide evidence for the multi-fold increase in the prevalence of binocular dysfunctions among school children (Jang & Park., 2015; Wajuhian, 2015; Hussaindeen et al, 2016a). The prevalence of NSBVA among school children between 7 and 17 years of age in south India is 30.8% (Hussaindeen et al, 2016a). Out of every 100 children screened, 31 children have a NSBVA, in comparison to 8–10 children who has a refractive error. Convergence insufficiency (CI), with a prevalence of 16% contributes to more than 50% of the visual morbidity among the types of NSBVA (Hussaindeen et al, 2016a).This high percentage of NSBVA requires the attention of a trained optometrist to screen for these BV anomalies in the community.

From a practical perspective, the purpose of vision screening is to diagnose any significant ocular dysfunction that can impair vision and cause potential visual morbidity, within a short frame work. The time factor is a key concern in any vision screening program for optimal use of resources. If a comprehensive BV assessment is to be performed in every school set-up, the time factor constraint reduces the efficacy of the vision screening program.

A receiver operating characteristic (ROC) curve analysis is done in a clinical set-up to determine cut-off points of BV parameters that group subjects as symptomatic and asymptomatic (Florkowski, 2008). In a recent clinical study on 33 subjects with symptomatic CI, Cacho-Martinez et al (2014) reported that NPC and binocular accommodative facility has the best diagnostic accuracy in detecting CI. The results of this study are only applicable to CI and also with a small sample size of CI with large near exophoria in this study, the cut-off points are not directly relevant to a community set-up with large ranges of BV parameters.

Thus, this study aimed to determine the most sensitive and specific BV tests that could pick up the NSBVA, in a large cohort of children in a school set-up.

5.2 METHODS

The methodology is detailed in Chapter 2.

5.3 RESULTS

Based on the ROC analysis on 920 children, NPC break point with penlight (NPC-PL), near PFV break, monocular accommodative facility (MAF) and the difference between near and distant phoria using the MIM card (MIM difference), distance NFV and PFV break and vergence facility were statistically significant ($p<0.001$). Maximum sensitivity and sensitivity was obtained for NPC-PL, near PFV break, MAF and the difference between near and distant phoria and the cut-off values for these parameters and other BV parameters are listed in Table 5.1. Figure 5.1 depicts the area under the curve for these four parameters.

TABLE 5.1 Sensitivity and Specificity for vergence and accommodation parameters in the diagnosis of overall non-strabismic binocular vision anomalies (NSBVA)

Parameter	ROC area under the curve (95% CI)	Sensitivity	Specificity
NPC –PL >7.5 cm	0.73 (0.69-0.77)	71.5%	60%
Monocular AF <10 cpm	0.75 (0.71 -0.79)	77%	65%
MIM difference >2 PD	0.63 (0.6-0.67)	61.1%	70%
Near PFV break <20 PD	0.76 (0.7-0.8)	70%	80%
Near NFV break <13 PD	0.5 (0.48-0.6)	60%	70%
Distance PFV break <15 PD	0.7 (0.66-0.76)	80%	60%
Distance NFV break <7 PD	0.58 (0.53-0.63)	60%	70%
Vergence facility <10 CPM	0.76 (0.7-0.8)	70%	80%

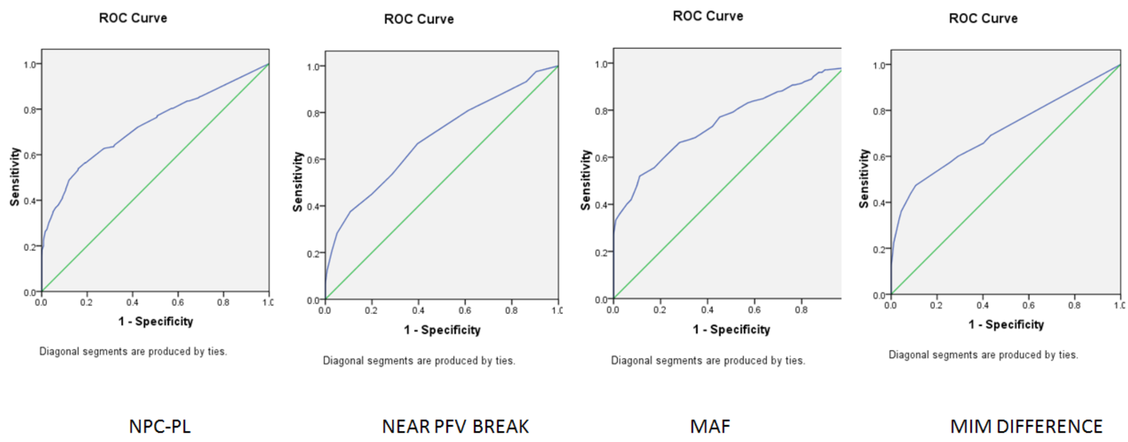

FIGURE 5.1 ROC curve for Near point of convergence with penlight (NPC-PL), Near Positive fusional vergence (PFV) break, Monocular accommodative facility (MAF) and difference between distance and near phoria assessed using muscle imbalance measure card (MIM difference)

Logistic regression was used to derive the predicted probabilities for net sensitivity and specificity for combination of parameters. The sensitivity and specificity achieved for the combination of two parameters was maximum for the combination of NPC-PL and MIM difference (Figure 5.2) and was 84% and 72.1% respectively (ROC area under the curve with 95% CI: 0.8 (0.76 – 0.83) p<0.0001). Similarly, for three parameters combination, statistically significant model was achieved for the combination of NPC-PL, MAF and MIM difference (p<0.0001). With the predicted probabilities for this combination, the area under the ROC curve was 0.85 (95% CI: 0.8 – 0.88) (Figure 5.3).

Based on these findings, 305 children (mean (SD) age: 12.7 (2) years) comprising of 121 male and 184 female were screened for NSBVA using these three BV parameters alone. Using the minimum battery of tests obtained through the ROC analyses, the prevalence of NSBVA was found to be 34%.

This minimum battery was then used to diagnose NSBVA in the original sample of 920 children. With just the NPC-PL cut-off and MAF, the prevalence estimate was found to be 28.4%. With the NPC-PL cut-off and difference between distant and near phoria, the prevalence dropped to 20.8%. With cut-off for MAF and difference between near and distance phoria, the prevalence rates further dropped to 16%. Hence, the combination of NPC-PL and MAF were estimated to be the best predictors.

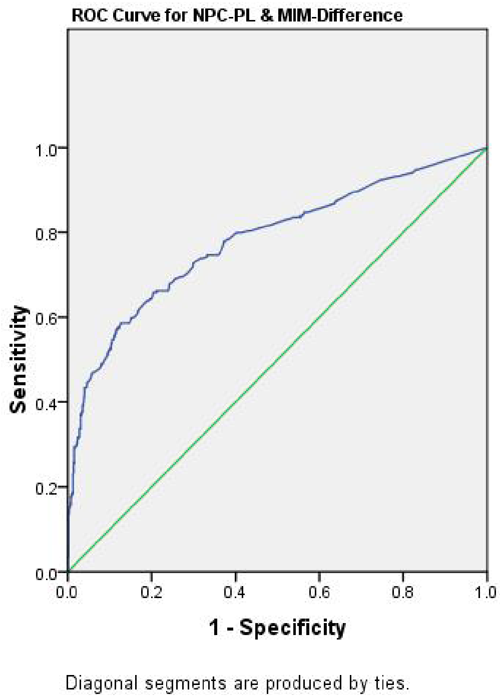

FIGURE 5.2 ROC area under curve for combination of NPC with PL, and difference between distance and near phoria

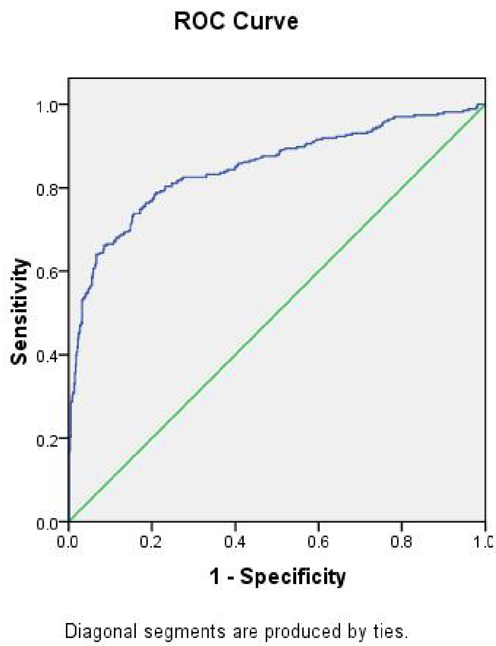

FIGURE 5.3 ROC area under curve for predicted probabilities obtained from the combination of NPC with PL, MAF and difference between distance and near phoria

5.3.1 Diagnosis of CI & AIF

CI was the highly prevalent (16%) of all the subtypes of NSBVA followed by AIF (10.1%). Prioritizing the detection of these two major types, ROC analyses revealed that NPC with penlight with a cut-off of >10 cm gives the highest sensitivity and specificity for the diagnosis of CI. For the diagnosis of AIF, monocular AIF, with a cut-off of < 7 CPM was the best predictor for screening (Table 5.2). With NPC and MIM, the prevalence of CI in the original sample was found to be 14.6% and with monocular AF, the prevalence of AIF was found to be 7.3%.

5.4 DISCUSSION

Based on the ROC analyses from this study, we propose that NPC with penlight, difference in distance and near phoria combined with monocular accommodative facility has the highest diagnostic accuracy for vergence and accommodative anomalies. When these three tests were applied in a cohort, the predictive estimates of prevalence were within 5% from the actual prevalence (Arya et al, 2012). The ROC for the predicted probabilities based on

TABLE 5.2 Sensitivity and specificity of significant BV parameters for the diagnosis of CI and AIF

Parameter	ROC area under the curve (95% CI)	Sensitivity	Specificity	Diagnosis
NPC-PL >10 cm	0.84 (0.8–0.88)	80%	73%	CI
NPC with accommodative target >5 cm	0.76 (0.7–0.8)	68%	70%	CI
Difference between distance and near phoria > 2 PD	0.79 (0.78–0.88)	77%	80%	CI
AF-Monocular <7 CPM	0.96 (095–0.98)	92%	90%	AIF
AF-binocular <8 CPM	0.9 (0.87–0.93)	88%	73%	AIF

the combination of these factors yielded 0.84 area under the curve. Thus, this minimum test battery can be recommended to diagnose NSBVA in a community set-up and in large epidemiological studies.

When this test battery was applied to the original cohort, the prevalence estimates were close to the actual prevalence for combination of NPC-PL cut-off and MAF (28.4%). The prevalence dropped down with other combination mainly because of the following reasons. This battery of test has a good representation of two vergence tests and one accommodation test thus ensuring that both accommodation and vergence anomalies are diagnosed with good accuracy. When the combination is restricted to just the vergence tests, the diagnostic accuracy comes down logically, leading to low prevalence estimates, as only vergence anomalies are identified from the cohort.

In clinical practice, there exists different cut-off points for standard clinical tests as proposed by various authors (Cacho-Martinez et al, 2014).Similarly, there exists considerable variability in the number of clinical signs used in the diagnosis of NSBVA. In classical presentations of NSBVA such as convergence insufficiency, there is good agreement about the near exophoria being large than distance. The CITT (Convergence Insufficiency Treatment Trial) study group based on evidence from various authors proposed the standard criteria for diagnosing CI (Scheiman et al, 2005). This includes exophoria at near greater than distance by ≥4 prism Diopters, receded NPC, and reduced near positive fusional vergence (PFV) range.

In recent study by Martinez et al (2014), NPC break > 5.35 cm, NPC recovery > 8.25 cm and binocular accommodative facility < 8.25CPM were estimated to have the best diagnostic accuracy in estimating the prevalence of CI in a clinical population. The sample size of the study was 33 and these findings are only pertinent to symptomatic CI subjects with large near exophoria as in a clinical set-up. To the best of our knowledge, no community-based data available to suggest the best predictors for NSBVA diagnosis. Based on a small clinical sample, Garcia et al (2000) suggested that monocular AF <8 cpm could best predict accommodative dysfunction.

As the prevalence of CI and AIF were the highest among all the sub-types of NSBVA, detecting these anomalies in a community set-up can be a high priority. For detecting CI, NPC with pen light (>10 cm break) and red filter has the highest sensitivity and for detecting AIF, monocular accommodative facility (<7 CPM) showed the best sensitivity. These two tests can play a crucial role in the diagnosis of the two most commonly prevalent NSBVA.

Our study has important implications for primary eye care and community optometry as this minimum test battery is a feasible model that ensures the diagnosis of NSBVA in a community. Such models are ideal to cater to the increasing visual morbidity due to NSBVA especially among the pediatric population.

The minimum test battery of difference between distance and near phoria, monocular accommodative facility and NPC-PL yield good sensitivity and specificity for diagnosis of NSBVA in a community set-up.

CHAPTER 6

EFFICACY OF VISION THERAPY IN A COMMUNITY SET-UP – PRELIMINARY RESULTS

ABSTRACT

Purpose: To report the efficacy of vision therapy in improving binocular vision parameters in a cohort of subjects with non-strabismic binocular vision anomaly (NSBVA) in a community set-up.

Methods: Following the prevalence estimates, children were categorized into diagnosis of NSBVA and normal binocular vision (NBV). Vision therapy for 10 sittings (45 minutes/day) was provided to a sub-group of children with NSBVA in the school set-up. BV parameters were reassessed following the vision therapy and home reinforcement was advised.

Results: Sixty-six children between 7 and 16 years of age were included in the study with a mean (SD) age of 11.3 (2.5) years. Statistically significant improvements were seen in BV parameters of NPC with accommodative target and penlight, near positive fusional vergence (PFV) recovery, distance PFV break, binocular accommodative facility, and vergence facility (paired *t*-test, $p< 0.05$). With vision therapy, subjective improvements in visual symptoms were noted in 60% of the study sample.

Conclusion: Innovative models of vision therapy as proposed in this study are feasible and viable models to combat visual morbidity due to the high prevalence of NSBVA in the community.

Key Words: convergence insufficiency; accommodative infacility; school vision screening; binocular vision; non-strabismic binocular vision anomalies; vision therapy

6.1 INTRODUCTION

In a pediatric population, the prevalence of a non-strabismic binocular vision anomaly (NSBVA) is 9.7 times more common than other ocular diseases (Scheiman et al, 1996). Recent population-based studies quote an alarmingly increasing statistic of 28.7% prevalence of NSBVA among primary school children in the community (Jang & Park, 2015). In our ethnicity, we (Hussaindeen et al, 2016a), have reported a prevalence of 30.8% symptomatic NSBVA among school children between 7 and 17 years of age.

This high prevalence of NSBVA does demand screening for BV anomalies followed by appropriate management to combat the visual morbidity due to NSBVA. The universally accepted management strategy for NSBVA is vision therapy (VT) (Scheiman & Wick, 2014). After appropriate refractive correction is provided, a structured vision therapy program to train accommodation and vergence has shown to be efficacious in improving the BV parameters, thus alleviating the visual symptoms (Scheiman et al, 2005). Vision therapy for a clinical population can be home based or in-office based. Home-based VT that include pencil push-up (PPU) and cat card exercise has been the conventional treatment modality followed for many years (Scheiman et al., 2008; Patwardhan et al, 2008). Though it lacks adequate scientific evidence, it is clinically popular for its simplicity and low cost. But, the convergence insufficiency treatment trial (CITT) group (Scheiman et al., 2008) has shown that, pencil push-ups are no more effective than placebo therapy in symptomatic convergence insufficiency (CI) in improving the clinical signs and symptoms. This adds complexity to the management perspective of NSBVA in the community. Prescription of simple exercises like PPU could potentially result in poor compliance and lack of adherence to therapy thereby resulting in treatment failure, especially in the pediatric population. Also, referral to a hospital-based set-up would result in loss to follow-up reducing the effectiveness of vision screening program. Thus, more innovative treatment options that are feasible at the community set-up are warranted. The aim of this study is to test the efficacy of vision therapy in a school set-up in an innovative structured way.

6.2 METHODS

The detailed methodology of BAND study is briefed in chapter 2. A written informed consent was obtained from the school administration and an oral assent was obtained from the children before the commencement of the study. Approval from the parents was obtained through the school administration prior to providing vision therapy in the school set-up.

The report of children with a diagnosis of NSBVA was sent to the school authorities and a meeting was conducted with the teachers and parents to brief about the condition and the role of vision therapy in improving the BV efficiency. Good support was obtained from two schools and one school was chosen first based on the large proportion of children with NSBVA in the particular school.

Seventy children out of the 94 children with NSBVA were willing to take up VT. Three physical education teachers in the school were trained to handle the vision therapy session on alternate days for 10 sessions, each session lasting for 45 minutes a day. A trained optometrist observed and supported the training sessions during the 10 days.

The vision therapy was provided using simple training equipment like Brock string, Barrel card, opaque and transparent eccentric circle, opaque and transparent life saver card, and accommodative flippers with word rock card and Hart chart (Scheiman & Wick, 2014). Written instructions and 10 sets of VT kit was provided to the school. The order of therapy and the specific procedures to be given for each child was printed out and handed over to the physical education teachers. The sequence of VT protocol was structured based on the recommendations by Scheiman & Wick (2014).The entire sample is divided between the three teachers and each teacher had to take care of around 23 children.

After 10 sessions of VT, reassessment of BV parameters was carried out after one week of the last session to ensure the sustainability of improvement. All the BV parameters that were measured in the baseline were re-measured by the principal investigator and the investigator was masked of the baseline measurements. Subjective improvement was assessed by asking two closed-ended questions: 1. “Did the vision therapy improve your visual symptoms?”, and 2. “Are you comfortable to reading now without symptoms?”

6.3 RESULTS

The demographics of the population are shown in Table 6.1. Out of the 283 children with NSBVA (Hussaindeen et al., 2016a), 94 children belonged to this particular school chosen

TABLE 6.1 Demographics of the study sample

Sample Size	**66**
Mean (SD) age (in years)	11.3 (2.5)
Age range	7–16
Male: Female	40:26
Convergence insufficiency (CI)	39
Convergence excess (CE)	4
Accommodative infacility (AIF)	23

for the vision therapy. Consent to participate in the 10 sessions of VT was obtained from 70 children. Fifteen children had upcoming final exams and thus could not allocate time for all the 10 sessions of the therapy. Nine children were not willing to participate in the study due to fear factor.

After 10 sessions of vision therapy, reassessment was performed for 66 children as two children did not turn up to the school on the day of reassessment and 2 children did not complete the 10 sessions.

The changes in BV parameters are illustrated in Table 6.2. Paired *t*-test revealed statistical significance for parameters of NPC break and recovery with accommodative target and penlight, near PFV recovery, distance PFV break, MEM accommodative response, binocular accommodative facility and vergence facility. Mean difference with 95% CI is provided for statistically significant parameters.

As CI and AIF were the two highly prevalent NSBVA, results of BV parameters pre and post VT are presented separately for these two anomalies, excluding the 4 children with CE. The changes in binocular vision parameters in CI and AIF are illustrated in Tables 6.3 and 6.4. Based on the CITT study protocol (Scheiman et al., 2005) for definition of success (NPC with AT <6 cm and Near PFV break <15 PD), 18 subjects (46.2%) were "successful" and 30 subjects (76.9%) "improved".

The proportion of subjects who felt subjective improvement was found to be 65.1% and 60.1% for the closed-ended questions: 1. "Did the Vision therapy improve your visual symptoms?", and 2. "Are you comfortable reading now without symptoms?"

TABLE 6.2 Changes in BV parameters pre- and post-VT

BV Parameters		Pre-VT	Post-VT	Mean Difference (95% CI)	Paired t-test p-value
NPC-AT (in cm)	Break	6.2 (5.1)	4.4 (3.3)	1.8 (0.3–3.2)	<0.05
	REC	8.5 (6.4)	6 (4.9)	2.5 (0.5–4.5)	<0.05
NPC-PLR (in cm)	Break	15.8 (8)	8 (6)	7.7 (4.1–11.3)	<0.001
	REC	20.5 (13)	12.9 (9.8)	7.6 (3.6–11.7)	<0.001
AA (in D)	M/O	10.7 (2.8)	11.4 (2.6)	NA	>0.05
	B/O	11.2 (3.3)	12.3 (3.3)	NA	>0.05
Near PFV (in PD)	Break	20.8 (10.5)	23.4 (11.7)	NA	>0.05
	REC	15.3 (8.3)	18.8 (10.6)	4 (0.3–7)	<0.05
Near NFV (in PD)	Break	14.1 (4.8)	13.6 (4.2)	NS	>0.05
	REC	10.7 (4.8)	10.3 (4)	NA	>0.05
Distance PFV (in PD)	Break	13 (6.3)	15.1 (5)	3.6 (0.3–4)	<0.05
	REC	8.9 (5.1)	10.3 (3.7)	NA	>0.05
Distance NFV (in PD)	Break	7.3 (2)	7.8 (1.7)	NA	>0.05
	REC	5 (1.9)	5.3 (1.7)	NA	>0.05
AF (in CPM)	M/O	6.8 (4)	7.4 (3.9)	NA	>0.05
	B/O	6.9 (3.7)	8.7 (3.5)	3.6 (0.7–3)	<0.01
VF (in CPM)		8.3 (4.1)	9.8 (3.4)	1.5 (0.2–3)	<0.01
MIM Horizontal (in PD)	Dist	–0.8 (2.7)	–0.2 (1)	NA	>0.05
	Near	–2.4 (4.4)	–2.4 (4)	NA	>0.05
MIM Vertical (in PD)	DIST	0 (0.4)	0 (0.1)	NA	>0.05
	NEAR	0 (0.4)	0 (0.4)	NA	>0.05
MEM (in D)		0.3 (0.2)	0.5 (0.2)	0.2 (0.1-0.3)	<0.001
AC/A		5 (1.3)	5.1 (1.2)	NA	>0.05

NPC-AT – Near point of convergence with accommodative target; NPC-PL – Near point of convergence with pen light and red filter; NPA – Near point of accommodation; NFV – negative fusional vergence; PFV – Positive fusional vergence; MIM – Muscle imbalance measure; MEM – Monocular estimate method; AF – Accommodative facility; VF – Vergence facility; CPM – Cycles per minute.

TABLE 6.3 Changes in binocular vision parameters pre- and post-VT in CI

BV Parameters		Pre-VT	Post-VT	Mean Difference (95% CI)	Paired t-test p-value
NPC-AT (in cm)	Break	6.9 (3.7)	4 (3.2)	2.8 (1.2–4.5)	<0.001
	REC	9.9 (5.2)	5.9 (5.1)	4 (1.3–6.6)	<0.001
NPC-PLR (in cm)	Break	18.6 (11.7)	8.4 (5.8)	10.1 (4.9–15.3)	<0.001
	REC	24.7 (11.7)	13.2 (9.7)	11.4 (6.1–16.7)	<0.001
Near PFV (in PD)	Break	17.8 (9)	24 (11.7)	6.2 (2–10.7)	<0.001
	REC	13.2 (7.1)	19.2 (10.8)	6 (2–10)	<0.001
MIM-Horizontal (in PD)	Near	–5 (4.2)	–3.3 (4.2)	1.5 (0.1 – 3)	<0.001

NPC-AT – Near point of convergence with accommodative target; NPC-PLR – Near point of convergence with pen light and red filter; PFV – Positive fusional vergence; MIM – Muscle imbalance measure

TABLE 6.4 Changes in binocular vision parameters pre- and post-VT in AIF

BV Parameters		Pre-VT	Post-VT	Mean Difference (95% CI)	Paired t-test p-value
AF (in CPM)	M/O	4 (2.8)	6.6 (3.6)	3 (0.5 -5.6)	<0.05
	B/O	4.2 (2.1)	7.5 (2.7)	3.5 (1.5-5.4)	<0.01
MEM (in D)		0.48 (0.2)	0.27 (0.2)	0.2 (0.08-0.3)	<0.01

AF – Accommodative facility; MEM – Monocular estimate method; CPM – Cycles per minute

All the children were advised to continue the present model of vision therapy in the school set-up and a review was planned after 3 months.

6.4 DISCUSSION

The BAND study utilized an innovative, feasible, and viable community model for vision therapy to children with NSBVA. After 10 sessions of vision therapy, significant improvement was seen in BV parameters of NPC, near PFV recovery, distance PFV break, accommodative and vergence facility. These are the key parameters that determine the visual efficiency of the BV system (Scheiman & Wick, 2014). Subjective improvements in visual symptoms could not be documented with existing validated questionnaire like the CISS due to its comprehension issues in our ethnicity (unpublished data).So we utilized a simple approach of asking closed-ended questions that assess the presence or absence of improvement related to visual symptoms and comfortable reading. Almost 60% of the children felt subjective improvements in near visual performance following VT.

The recommended protocol for vision therapy sessions are generally 12 to 24 office visits with home maintenance therapy depending on the severity of the condition (Scheiman & Wick, 2014). This protocol may not work in the community-based set-up due to loss to follow-up and cost factor associated with in-office hospital-based VT. The protocol in this study was adopted based on our clinical experience, wherein we provide 10 sessions of in-office vision therapy (IVT) 45–60 minutes per day on consecutive or alternate days followed by 3 months of home vision therapy (HVT). We have observed significant success with this approach and thus utilized the same in a community set-up. Though IVT practice is extensive and sophisticated with computer and manual based therapy, we tried out simple manual mode of therapy in the community.

Vision therapy is gaining increasing evidence in the literature, especially after the multicentric RCT by the CITT study group in the US (Scheiman et al., 2005). As CI is the highly prevalent NSBVA (Jang & Park, 2015; Hussaindeen et al., 2016 a) considerable evidence is focused towards the efficacy of VT in CI. In India, considerable uncertainty exists regarding the best treatment for CI among eye care professionals. Results of surveys conducted among eye care practitioners regarding the treatment modalities for CI revealed that 3478.8% recommend pencil push-up (PPU) exercises, 22% prescribe other home-based VT with PPU, 5–22% prescribe in-office VT including synoptophore exercises, 10–20% prescribe base-in prisms, 13% prescribe reading glasses alone, 3–18% refer to optometrist practicing VT, and 6–8% do not prescribe any treatment. Interestingly, 69% of optometrist and 4% of ophthalmologist felt that a structured in-office VT would be more effective than any other treatment modalities (Scheiman et al., 2002; Patwardhan et al., 2008). This study adds evidence to the efficacy of VT in a community-based set-up.

It is important to emphasize that the objective improvements in BV parameters did not reach the desirable normal levels for clinical significance. Among the 66 subjects, 60% of the subjects were reported improvements in subjective symptoms. This is comparable with the CITT study (Scheiman et al., 2005), wherein after 12 weeks of IVT in a clinical set-up, 75% of subjects showed improvements. It is also recommended that minimum 20–30 sessions would be needed for clinically significant improvements in objective parameters (Scheiman & Wick, 2014). The CITT study used computer based techniques and our study used manual techniques and this difference in VT protocol between the studies could have impacted the outcome. Also extended sessions could bring in improved outcomes of VT.

Support from school administration is the key factor with such innovative approach. Similarly, the teachers' cooperation and their interest in the child's health care also play a major role in the success of this program. As this model was tried out for the first time, a trained optometrist was present in the school set-up to monitor the program during the 10 days of VT. However, the same approach can be followed even without the optometrist presence, provided good support is ensured from the teachers. Computer-based VT can be a solution to the follow-up factor. Online tracking facilities available with computer-based VT can enhance the follow-up and also can definitely bring in more interest and improve compliance especially among children. Future studies should also focus on assessing the sustainability of improvement following home vision therapy. We are currently working on a feasible model to implement the same. Follow-up as planned in this study could not be executed due to unprecedented natural calamity that occurred in this part of the country. Also inability to obtain permission from the school administration, and tracing the students were practical difficulties faced with the follow-up. This is a potential limitation of the study.

Through this study, we suggest a feasible and viable model for community-based approach to vision therapy. Though this model needs further exploration, such model can play a significant role in reducing the visual morbidity due to highly prevalent visual dysfunctions such as NSBVA.

CHAPTER 7

HOSPITAL-BASED PREVALENCE OF CONVERGENCE INSUFFICIENCY IN A TERTIARY EYE CARE CENTER

ABSTRACT

Purpose: To estimate the prevalence of convergence insufficiency (CI) at a tertiary eye care center in Southern India.

Methods: One year clinical records (January 2014–December 2014) of 3584 patients on whom binocular vision (BV) assessment was done was reviewed for demographic and clinical characteristics. Subjects aged between 9 and 35 years with complete BV assessment records and visual symptoms associated with near work were filtered. CI was classified according to the following characteristics: (a) receded near point of convergence (NPC) >6 cm break, (b) exophoria at near>4 prism diopters (PD) than distance and (c) positive fusional vergence (PFV) <15 PD base out at near.

Results: Out of 3584 records, 1858 subjects met the inclusion criteria for age with complete records of the BV parameters. Out of the 1858 subjects, 13.2% (246/1858) of the data met the eligibility criteria for age with complete record of phoria, NPC, and PFV. The mean age of the sample was 22.3 ± 7 years comprising of 136 male and 110 female. The mean NPC (objective break) was 12.4 ± 6.3 cm. The mean near exophoria was 5.7 ± 3.7 PD. The mean PFV (break) for near was 17.2 ± 7.5 PD. The prevalence of definite CI (all three signs positive) was 28.5%.

Conclusion: These findings indicate a high prevalence of CI in a hospital-based population.

Key Words: Convergence insufficiency, Exophoria, Near point of convergence, Positive fusional vergence

7.1 INTRODUCTION

CI is the most common non-strabismic BV disorder with prevalence estimates varying between 1.75% and 33% in different studies (Porcar et al., 1997; Rouse et al., 1999; Scheiman et al., 1996; Cacho-Martinez et al., 2014). This variability could be attributed primarily to the difference in diagnostic criteria for CI used in various studies. CI presents with near work symptoms including asthenopia, sleepiness, loss of concentration, and intermittent double vision. Common clinical signs in CI include receded NPC, high near exophoria as compared to distance phoria, and reduced PFV (Barnhardt et al., 2012; Borsting et al., 2012).

Recent population-based studies (Jang & Park, 2014) indicate a high prevalence of 13% of CI among primary school children. The recent data on hospital-based prevalence of CI across the world is more than a decade old, (Lara et al., 2001; Scheiman et al., 1996) and in the Indian ethnicity, more than two decades old (Dhir, 1961; Deshpande & Ghosh, 1991). This becomes important to understand the current burden of the disease in a hospital-based set-up to plan to appropriate interventions.

Receded NPC > 6–8 cm is still followed as the standard and only diagnostic criteria used for CI across the country. With recent literature that emphasizes a set of diagnostic criteria be used in the identification of CI (Scheiman et al., 205; Scheiman & Wick, 2014), it becomes important to understand the clinical characteristics of CI in a large cohort.

The overall objective of this study is to provide a current perspective on the prevalence of CI among the BV anomalies at a tertiary eye centre in South India and also to profile the clinical characteristics of CI in the indigenous population compared to other ethnicities. This study also served as a pilot study to understand the prevalence of CI prior to the commencement of the binocular vision anomalies and normative data (BAND) study.

7.2 METHODS

Clinical records of 3584 patients on which BV assessment was done in the binocular vision clinic of Sankara Nethralaya (A unit of Medical Research Foundation, Chennai, India) were selected from electronic medical records and reviewed systematically. Records were reviewed for demographic and clinical data seen between 1st January 2014 and 31st December 2014. With the inclusion criteria of age between 9–35 years and with complete records of all BV parameters, 1858 records were filtered. The records of the patients with a complaint of asthenopia, headache, eyestrain, and eye-pain during near work were noted as symptomatic.

Inclusion Criteria

- Age between 9 and 35 years.
- Visual acuity 6/9 or better with habitual correction.
- Normal accommodative amplitudes of age as defined by Hofstetter's minimum expected amplitude of accommodation.

Exclusion Criteria

- Strabismus
- Amblyopia
- Attention deficit hereditary disorder (ADHD) or any other neurological disorder
- Uncorrected refractive error greater than or equal to –0.50 to +1.00 DS, and >1.00 D of astigmatism in either eye and
- Anisometropia of >1.00 D

CI was classified according to following characteristics (Scheiman et al., 2005; Scheiman & Wick, 2014).

Direct Signs

- Exophoria at near >4 PD than distance
- Reduced PFV (≤15 PD base out (BO) blur or break)
- Receded NPC (>6 cm break)

Indirect Signs

- Difficulty with plus lenses in accommodative facility testing with accommodative facility <6 cycles per minute (CPM).
- Reduced negative relative accommodation (NRA) <+1.50 DS.

Records meeting the eligibility criteria were further reviewed for CI-diagnostic measures which include, heterophoria for distance and near, PFV for near (blur, break, and recovery), NFV at near (blur, break, and recovery), and NPC (both subjectively and objectively) with a linear target and penlight with red filter test. The definition used for CI was adopted from the convergence insufficiency treatment trial (CITT) study (Scheiman et al., 2005). For this study, any subject with two or more criteria in the definite signs were classified as having CI. Subjects with two signs positive were classified as suspect CI and three signs positive were classified as definite CI.

7.3 DATA ANALYSIS

SPSS V.18.0 and Microsoft XL software tools were used for statistical analysis. The mean and standard deviation of the BV parameters were analyzed. Proportion of subjects with all three definite signs and with additional signs was calculated. Pearson's correlation was used to correlate between BV parameters.

7.4 RESULTS

246/1858 (13.2%) of the data met the eligibility criteria having a complete record of the phoria, NPC, and PFV. The mean age of subjects was 22.3 ± 7 years comprising of 136 male and 110 female. 34% of subjects were in the age range of 9–18 years and 66% of CI subjects were in the age range of 19–35 years.

Myopia of greater than –0.25 DS was present in 24 subjects (10%), hyperopia of greater than +0.50 DS in 15 subjects (6%) and astigmatism of greater than 0.50 D in 48 subjects (20%).

The proportion of definite CI (all three signs positive) and suspect CI (two signs positive) is enumerated below (Table 7.1). Out of the 246 subjects, 77 subjects (31.3%) fulfilled Sheard's criterion (Sheard, 1930) for near PFV. Also, 121 out of the 246 subjects (49%) had an additional accommodative dysfunction of difficulty with plus lenses in accommodative facility testing.

The BV parameters of the clinically diagnosed CI have been summarized in Table 7.2.

Out of the 146 subjects, 21 (14%) subjects had normal NPC with accommodative target (AT), in the presence of more than 4 PD difference between distance and near exophoria. 92 (37%) subjects had near PFV> 15 PD, in the presence of receded NPC >6 cm and more than 4 PD difference between distance and near exophoria. 121 (49%) subjects

TABLE 7.1 Prevalence of CI definite and CI suspect

Criteria	N (%)
All three signs positive	70 (28.5%)
Receded NPC> 6 cm + distance – near exophoria difference of >4 PD	100 (40.6%)
Receded NPC> 6 cm + near PFV break less than 15 BO	87 (37%)
Distance – near exophoria difference of >4 PD + near PFV break less than 15 BO	55 (22.4%)

TABLE 7.2 Binocular vision parameters of CI subjects

Binocular Vision Parameters	Mean (SD)
NPC break/recovery (with accommodative target) (in cm)	12.4 (6.3)/15.3 (6.9)
NPC break/recovery (with penlight and red filter) (in cm)	25 (9)/27.5 (8.4)
Difference between penlight and accommodative target (AT) NPC break	13.6 (8.4)
Near exophoria (in PD)	5.7 (3.7)
Accommodative convergence/accommodation (AC/A) ratio (heterophoria method)	4.3 (1.3)
Near PFV break/recovery (in PD)	17.2 (7.5)/14 (6.4)
Vergence facility (in CPM)	9.4 (4.4)
Binocular accommodative facility (in CPM)	7 (4)
Negative relative accommodation (NRA) in diopters	2.4 (0.5)
Monocular estimate method retinoscopy (MEM)	0.6 (0.2)

had a receded NPC>6 cm, even when the difference between near and distance exophoria is lesser than 4 PD.

Statistically significant negative correlation was obtained between NPC with AT and near PFV (Pearson's r –0.2, $p< 0.0001$) suggesting that increasing values of NPC is correlated with reducing values of near PFV. Statistically significant positive correlation was seen between near exophoria and near PFV (Pearson's r –0.2, $p < 0.0001$) suggesting that larger values of near exophoria are correlated with reduced near PFV. There was no significant correlation between near exophoria and NPC with AT or penlight.

7.5 DISCUSSION

The results of present study point out that, the prevalence of CI based on standard clinical criteria for diagnosis is 28.5% in a hospital-based population in the Indian ethnicity. This suggests that there is an increase in the hospital-based prevalence compared to statistics that showed 7% prevalence in a similar set-up of BV practice, almost two decades before (Dhir, 1961; Deshpande & Ghosh, 1991).

In the earlier study, there was lack of information regarding the clinical characteristics of CI and the criteria for diagnosis adopted. This study with well-defined criteria identifies that almost 28.5% of subjects between 9–35 years have CI. This study also revealed that the prevalence of CI is higher among the 18–35 years compared to children. This could be hypothesized due to the increasing near visual demands related to occupations, compared to an academic environment.

It is important to emphasize the clinical characteristics that are seen in patients with CI in our population. Receded NPC >6 cm break, is the commonest criteria used in the diagnosis of CI worldwide (Scheiman & Wick, 2014). But to understand the spectrum of CI, it becomes important to understand the profile of subjects with varying representations of clinical signs and are still symptomatic. With this approach, we are able to represent the profile of CI in our ethnicity in a large hospital-based sample.

In CI, large emphasis is based on the receded NPC and its association with near exophoria. But surprisingly, we did not see any significant correlation between these two factors, but rather observed significant correlation between NPC vs. near PFV and near exo vs. near PFV. Thus, near PFV is a common factor that drives vergence mechanisms of NPC and near exophoria. With emphasis on near PFV, many authors (Rouse et al., 1999; Scheiman et al., 1996, 2005; Lara et al., 2001; Scheiman & Wick, 2014) have used Sheard's criterion (Sheard 1930, 1983) of near PFV amplitudes lesser than twice the magnitude of the near exophoria as a universally accepted criterion in the classification of CI. But we found that only 31.3% of our study subjects fulfilled the

Sheard's criteria. This suggests that, the clinical signs and symptoms in CI may not be solely based on the Sheard's criterion.

It is interesting to note that, only 28.5% of the study sample had entire three definite signs positive for the diagnosis of CI. Another important clinical characteristic noted that the profile of exophoria is in our CI sample. Though, the CITT used criteria of minimum 4 PD difference between distance and near exophoria as a diagnostic criteria. Based on the diagnostic cut-off obtained from the BAND study (Hussaindeen et al, 2016a), we found that 49% of subjects had a clinical diagnosis of CI with receded NPC of >6 cm with >2 PD difference between distance and near exophoria. With the re-set criterion of minimum 2 PD difference between distance and near exophoria, 184/246 (74.8%) subjects had a receded NPC >6 cm. Among the study subjects, 40.6% had normal PFV even in the presence of receded NPC and difference between distance–near exophoria by >4 PD. And only 77 subjects (31.3%) fulfilled Sheard's criterion for near PFV.

A high percentage of subjects (49%) had an additional accommodative dysfunction of difficulty with plus lenses in accommodative facility testing. It has been hypothesized that subjects with CI tend to use excessive reflex accommodation to overcome the reduced PFV at near, thus resulting in associated accommodative excess (Scheiman & Wick, 2014).This was evident only in accommodative facility testing, with normal NRA and MEM retinoscopy values.

There are few limitations to our study. Firstly, the data is retrospective and thus influenced by multiple examiners making clinical measurements. Secondly, prevalence is based on hospital based sample may not be extrapolated to community and demand population-based studies to comment about the same.

This study brings out the high prevalence of CI in a hospital-based population and also points to out the varying clinical spectrum of CI. This study emphasizes that CI may not strictly follow conventional criteria of receded NPC alone and thus need a holistic approach to the diagnosis and management perspective.

CHAPTER 8

ETHNICITY-BASED DIFFERENCES IN THE INTERPRETATION OF A SURVEY –OUR EXPERIENCE WITH THE CONVERGENCE INSUFFICIENCY SYMPTOM SURVEY IN A HOSPITAL BASED INDIAN POPULATION

ABSTRACT

Purpose: To evaluate whether the convergence insufficiency symptom survey (CISS) score can be included in the diagnostic criteria of convergence insufficiency (CI) in Indian population.

Methods: Clinical records of 5917 subjects who reported to the binocular vision (BV) clinic between January 2013 and December 2014 were selected from electronic medical records and reviewed. 2568 out of the 5917 (43.4%) had asthenopic symptoms related to near work and reading and underwent a comprehensive BV assessment. Records are meeting the eligibility criteria of CI [(a) exophoria at near: >4 PD than distance (b) positive fusional vergence (PFV) for near: ≤15 prism base out (BO) blur or break (c) receded near point of convergence (NPC): >6 cm break] were analyzed. The median CISS scores of this hospital-based CI sample were compared with the cut-off scores proposed by Convergence Insufficiency Treatment Trial (CITT) group.

Results: 11.1% (284/2568) of the subjects had complete records of BV parameters and CISS survey with a diagnosis of CI. The mean age of the CI sample was 25.3 ± 9.4 years (range: 9–58 years). The median CISS score was 19 [(inter quartile range, IQR: 10–26)] for age group 9–18 years and 20 (IQR: 10–30) for age group 19–35 years in subjects diagnosed with CI as opposed to the cut-off score of ≥16 for children (9–18 years) and ≥21 for adults (19–35 years) proposed by the CITT study group in the Caucasian ethnicity. The overall ratio of CISS pass/fail was 139:145.

Conclusion: CISS needs validation and modification due to comprehension issues in the Indian population.

Key Words: Convergence insufficiency, Convergence insufficiency symptom survey, Convergence insufficiency symptoms, Convergence insufficiency screening

8.1 INTRODUCTION

CI is a common binocular vision disorder (Letourneau et al., 1979, 1988; Porcar et al., 1997; Rouse et al., 2009) with visual symptoms of asthenopia, sleepiness, headache, intermittent blurred vision for near, double vision and eyestrain while performing near tasks (Scheiman et al., 2008; Barnhardt et al., 2012). Common signs reported in CI include: 1) exophoria greater at near than distance, 2) a receded NPC, i.e., a break value in NPC greater than 6 cm, or 3) decreased positive fusional convergence (PFC) at near (Rouse et al., 2009). Prevalence of CI varies considerably in the literature ranging from 1.75% to 33.0% in different studies (Dwyer, 1992; Cooper & Duckman, 1978; Dhir, 1961; Desai et al., 1990; Deshpande & Ghosh, 1991; Gupta et al., 2008). In India, the prevalence of CI ranges from 3.9% to 49% (Dhir, 1961; Desai et al., 1990; Deshpande & Ghosh, 1991; Gupta et al., 2008).This considerable variation in the prevalence is due to differences in the population studied (children or adults/hospital-based or community-based sampling), and the diagnostic criteria used.

Patient surveys can play a significant role in studying the severity of a specific disorder and to monitor the effect of treatment. Surveys in health sciences are designed to assess the quality of life, quantify symptoms, and to assess the impact of treatment (Scheiman et al., 2008). Some of the common surveys available to measure the visual discomfort symptoms include the Convergence Insufficiency Symptom Survey (CISS) (Borsting et al., 2003; Rouse et al., 2004), College of Optometrists in Vision Development – Vision Related Quality of Life (COVD-VRQOL) survey (Maples, 2000), and the Conlon symptom survey (Conlon, 1999). Recent study indicates that both CISS and Conlon surveys are equally effective in predicting chronic symptoms (Pang et al., 2012). Vision science researchers and clinicians are now widely using these surveys in different countries, however, these surveys need to be validated for each country due to differences in the culture, ethnicity, and language (Garcia et al, 2014).

The CISS was developed by the CITT, a large multicentric trial that studied the effective treatment modality of CI (Borsting et al., 2003; Rouse et al., 2009). The CISS was developed to quantify and estimate the frequency and severity of symptoms reported by individuals (both children and adults) with symptomatic CI (Borsting et al., 2003; Rouse et al., 2004), and was validated with high internal consistency to monitor the treatment of CI before and after therapy. CISS allows two-factor analyses: whether the symptoms are present and if present how frequently they occur. It contains a set of 15 questions and the scoring is based upon a 5-point scale (0 = Never, 1 = infrequently, 2 = Sometimes, 3 = fairly often, 4 = Always). CITT proposed a cut off score of ≥16 for children (9–18 years) and ≥21 for adults (19–35 years). Two categories of subscales, namely the performance-related subscale and eye-related subscale constitute to the 15 items on the CISS.5 The performance-related subscale consisted of 6 symptoms (items 4, 5, 6, 9, 14, 15) related to visual efficiency when reading or performing near work and the rest of the 9 symptoms (items 1, 2, 3, 7, 8, 10–13) represent the eye-related subscale specific to visual function or asthenopic-type complaints. In the CITT sample of 221 children between 9 and <18 years of age, the performance-related symptoms such as losing place and losing concentration had a higher percentage of children reporting "most often" or "always" compared to eye-related symptoms such as pulling feeling around the eyes and words moving on the page. Also, boys had higher performance-related symptoms than girls and children of white ethnicity had higher eye-related symptoms in this sample. Hence, it is worthy to understand the cultural and ethnicity-based differences in the understanding of the CISS in a country like India with greater cultural diversity and multiple vernacular languages. Hence, this study is designed to determine if the CISS cut-off values determined on the United States population are applicable for patients in India.

8.2 METHODS

Clinical records of patients diagnosed to have BV anomalies at the binocular vision and vision therapy clinic of Sankara Nethralaya (Unit of Medical Research Foundation), Chennai, over a one year period (January–December 2013) were retrospectively reviewed. Clinical records of 5917 subjects were retrieved through electronic medical record system and were reviewed based on the inclusion/exclusion criteria.

The inclusion criteria set for CI (Scheiman et al., 2008) were as follows:

- BCVA ≥6/9, N6 (appropriate refractive correction)
- Near exophoria > 4Δ than far
- Receded NPC of >6 cm break
- Near PFV <15Δ BO blur or break
- Stereopsis better than 100 arc seconds
- Age greater than 9 years

Symptomatic CI was defined as the presence of symptoms of headache and eyestrain while reading or writing, diplopia, eye fatigue, associated with near vision tasks such as reading, using computers, playing games, etc. All the clinically diagnosed symptomatic CI subjects were filtered from the overall records and the CISS scores along with the BV parameters were compiled. The CISS in our study was self-administered to patients who are fluent with English and only these records were included for the study. The diagnosis of CI was based on the standard criteria for CI (Scheiman et al., 2008) diagnosis and this was verified by two senior optometrists for all the patients. After the retrospective audit is done, the CISS scores of our sample were compared with the cut-off proposed by the CITT study group (Borsting et al., 2003; Rouse et al., 2009). Statistical analyses were performed using the SPSS Inc. V.17.0 and Microsoft XL 2007.

8.3 RESULTS

Out of 5917 subjects, 2568 (43.4%) subjects had asthenopic symptoms related to near work and reading, with a diagnosis of a non-strabismic binocular vision anomaly (NSBVA) and had details of BV assessment. 11.1% (284/2568) of the data had complete records of the BV parameters along with CISS scores and met the eligibility criteria for a diagnosis of CI.

The mean age of the sample was 25.3 ± 9.4 years (range: 9–58 years). Out of the 284, 147 were males. Based on the CITT cut-off for CISS, the 284 subjects with the diagnosis of clinical CI were categorized as CISS pass and pail. The CISS pass/fail percentages for various age groups are summarized in Table 8.1.

The median CISS score obtained for the overall sample with the clinical diagnosis of CI was found to be 20 (IQR: 10-28.25). The overall ratio of CISS pass/fail was 139:145. The median score of each age group has been summarized in Table 8.2.

TABLE 8.1 Age-wise distribution of symptomatic and asymptomatic CI based on CISS score (n = 284)

Age Category (in years)	CISS Pass (n)	CISS Fail (n)
9–<18	28	42
18 and above	111	103
Overall (n = 284, %)	**139, 48.9%**	**145, 51.1%**

TABLE 8.2 Median CISS score based on age group (n = 284)

Age group (in years)	Median CISS Score	IQR
9–<18	19	10–26
18–35	20	10–30

When the response scores for each item were looked at, >50% of the CI subjects had reported "never" to items 7, 8, and 14. These items target symptoms of double vision, words moving on the page, and losing place while reading respectively. >45% of subjects responded never to items 9, 12, 13, and 15 that target at reading slowly, pulling feeling, words blurring, and re-reading the same lines. The responses are summarized in Table 8.3.

The percentage of subjects who responded fairly often or always to the performance-related and eye-related symptoms are depicted in Figure 8.1 below. The gray shades represent performance-related symptoms and the black shades represent eye-related symptoms. Comparatively, higher percentage of responses were seen in the performance-related symptoms.

The relevant BV parameters of the CI sample are summarized in Table 8.4.

8.4 DISCUSSION

The CISS has been designed by the CITT study group to assess the presence and frequency of symptoms in CI. When the relationship between patient characteristics and symptoms severity was assessed at baseline (Barnhardt e al., 2012) it has been found that performance-related symptoms were higher than eye-related symptoms in children with

TABLE 8.3 Percentage of responses for each option in the 15 items of the CISS

		Percentage of responses for each option				
S. No	**Item**	**Never**	**infrequently**	**sometimes**	**fairly often**	**always**
1.	Do your eyes feel tired when reading or doing close work?	16%	11%	39%	19%	16%
2.	Do your eyes feel uncomfortable when reading or doing close work?	27%	13%	32%	17%	11%
3.	Do you have headaches when reading or doing close work?	31%	11%	26%	18%	14%
4.	Do you feel sleepy when reading or doing close work?	33%	11%	28%	15%	13%
5.	Do you lose concentration when reading or doing close work?	26%	12%	31%	19%	12%
6.	Do you have trouble remembering what you have read?	36%	16%	30%	12%	7%
7.	Do you have double vision when reading or doing close work?	57%	12%	18%	8%	5%
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?	76%	8%	9%	4%	4%
9.	Do you feel like you read slowly?	46%	12%	24%	9%	9%
10.	Do your eyes ever hurt when reading or doing close work?	39%	13%	31%	7%	10%
11.	Do your eyes ever feel sore when reading or doing close work?	41%	18%	23%	8%	10%
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?	46%	15%	22%	11%	6%
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?	47%	11%	20%	14%	7%
14.	Do you lose your place while reading or doing close work?	52%	12%	18%	12%	6%
15.	Do you have to re-read the same line of words when reading?	47%	16%	20%	11%	6%

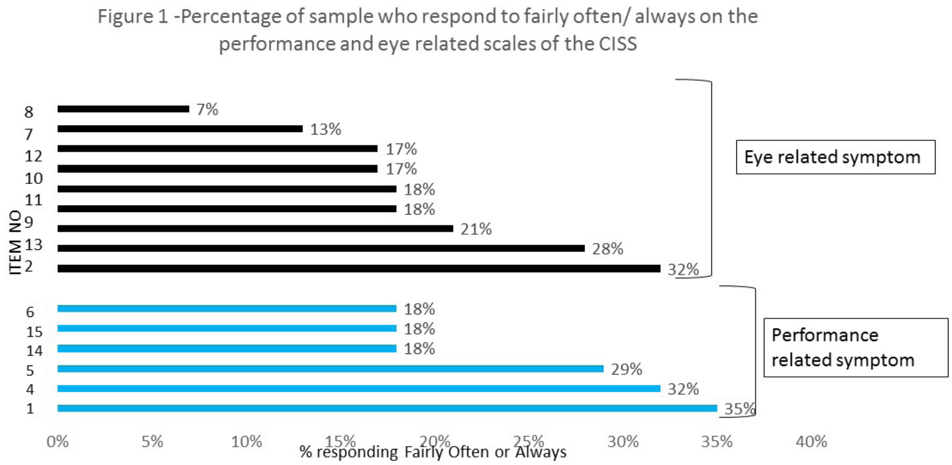

FIGURE 8.1 Performance-related and eye-related symptoms in the CISS

TABLE 8.4 Binocular vision parameters of CI subjects (n = 284)

Binocular Vision Parameters	Mean (SD)
NPC break/recovery (with penlight and red filter) (in cm)	22.1 (9)/26.5 (9.7)
Near PFV break/ recovery (in prism diopters)	19.3 (9.3)/15.3 (7.9)
AC/A ratio (heterophoria method)	5 (1.1)
Near exophoria (in prism diopters)	5.1 (3.9)

CI, with ethnicity and gender-based differences in response. This study indicates that in a tertiary eye care set-up in India, majority of clinically diagnosed symptomatic CI (48.9%) pass the CISS, according to the cut-off provided by the CITT study group. The clinical diagnosis of CI based on the patient's symptoms correlated well with the clinical signs as depicted by the BV parameters of NPC, near PFV, and near exophoria. The CISS was developed as a tool to measure the effect of treatment and monitor symptoms in a clinical trial by CITT (Borsting et al., 2003; Rouse et al., 2004). The study group has also done the validation of the CISS in a systematic way and have found it to be useful to differentiate between symptomatic CI from those with normal BV in an ethnically mixed sample at the United States. CISS is readily available and has been widely used in many places (hospital and clinics) in India and other countries to quantify symptoms in CI and to monitor changes in symptoms after vision therapy. The findings in our study suggest that CISS, validated for use with a population of patients with English as the first language, may not be useful as a standalone test to differentiate patients with CI from those with normal BV before further validation is done in Indian population.

There exists a mismatch between what clinicians consider ocular symptoms, what patient considers ocular symptoms and how much (or even whether), they relate to the objective findings. Our findings suggest that comprehension and understanding of questions, can complicate the direct interpretation of surveys as in the case of CISS in our population. Although, 48.9% of our sample population passed the CISS, they all were clinically diagnosed CI and presented with ocular symptoms and asthenopia that clinicians considered to be significant. It is apparent that validation of the CISS with different ethnic groups may be necessary to enable its use in countries outside the United States. We also observed a similar trend as reported by the CITT study group (Barnhardt e al., 2012) for the higher percentage of respondents to the performance-related symptoms compared to the eye-related symptoms. Higher percentage of boys reported increased performance related symptoms and black children had lesser eye-related symptoms in the CITT study group. This reflects gender- and ethnicity-based differences in the responses to CISS.

India is a multilingual country with its population widely spread in rural as well as urban areas and patients with different educational backgrounds and languages seeking eye care. Hence, it is important to validate the existing questionnaire from the comprehension perspective and translate to vernacular languages. A questionnaire like the CISS is quite useful for monitoring symptoms in symptomatic CI. However, comprehension of the questions may be a concern depending on the ethnicity being tested, especially in an ethnically diverse country like India. Based on the distribution of responses to the 15 items in CISS, items 7, 8, and 14 appear to be poorly understood by Indian CI subjects. It is surprising to note that most of the subjects did not report "double vision" as a symptom, though it is considered as one of the common symptom in CI. This raises query on the understanding of what patients perceive as double, and in self-administered questionnaire like CISS, this would need further clarification and simplification in a population where English is not the first language. Also other words such as "words jumping and moving" and "losing place" were found to be difficult for the patients to comprehend. Recently, validation and translation of CISS has been done for Portuguese population that showed good internal reliability and temporal stability among university students (Tavares et al., 2014). The future scope of this study will focus on the validation and modification of CISS for Indian population.

Convergence insufficiency symptom survey may not be used as a standalone test to differentiate symptomatic CI from those with normal BV in patients in India. The CISS requires validation and modification for use with Indian CI subjects. The modified and validated Indian version of CISS will help clinicians to monitor and assess the change in the symptom level after treatment in clinical practice in India.

CHAPTER 9

RESULTS OF CONVERGENCE INSUFFICIENCY SYMPTOM SURVEY AND ACADEMIC BEHAVIOUR SURVEY IN THE BINOCULAR VISION ANOMALIES AND NORMATIVE DATA STUDY

ABSTRACT

Purpose: To report the results of the convergence insufficiency symptom survey (CISS) and academic behavior survey (ABS) in a cohort of school children in south India.

Methods: This population-based cross-sectional study came up with prevalence estimates of non-strabismic binocular vision anomalies (NSBVA) and normative data of binocular vision (BV) parameters among school children in Tamilnadu. 3024 children between 7 and 17 years of age were screened in the four schools and 920 children were included for the study. Estimates of normative data were done in the first phase followed by estimates of prevalence of BV anomalies based on the cut-off derived from the normative data. Children were categorized into 2 groups of NSBVA and normal binocular vision (NBV). Vision related quality of life (VR-QOL) was assessed using the CISS and ABS that were administered to all children during the initial screening process. Academic performance reports were obtained from school administration.

Results: Out of the 920 children, 30.8% of children had NSBVA and 69.2% children had normal binocular vision. Convergence insufficiency was the most prevalent (16%) among all the types of NSBVA. The CISS scores were statistically significant between the NSBVA and NBV group (median scores: CISS in NSBVA: 7; NBV: 4- Mann–Whitney U test, $p < 0.05$). The academic performance scores and ABS scores did not differ significantly between NSBVA and NBV- Mann–Whitney U test, $p < 0.05$ (median scores:

academic performance in NSBVA & NBV: 80%; ABS in NSBVA & NBV: 7). Significant association was seen between academic performance scores and CISS and ABS (Chi-square; $p < 0.001$) in the overall sample.

Conclusion: From the current study, no significant association was obtained between academic performance and the presence of a NSBVA. However, significant correlation was established between academic performance and CISS; Children who have low level of visual symptoms have better academic achievement.

Key Words: convergence insufficiency; accommodative infacility; school vision screening; binocular vision; non-strabismic binocular vision anomalies; convergence insufficiency symptom survey; academic behavior survey

9.1 INTRODUCTION

The CISS is a questionnaire used in the convergence insufficiency treatment trial (CITT) study (Borsting et al., 2003; Rouse et al., 2004; Barnhardt et al, 2012) to quantify symptoms before and after vision therapy in convergence insufficiency (CI). Further details of the CISS are elucidated in chapter 8.

The ABS is a tool utilized by the CITT study group to understand academic behaviors in children with CI, with and without the presence of parent-reported attention deficit hyperactivity disorder (ADHD) (Rouse et al, 2009). ABS is a 6-item survey that evaluates concerns about school performance and its association with performance behaviors during reading or performing school work. Each item is scored on a 4-point scale from 0 (Never) to 4 (Always) with a total score ranging from 0 to 24. This study reported that children with CI with parent report of ADHD scored higher on the ABS compared to children with normal binocular vision. This study concluded that a high proportion of children with CI also have learning difficulties thus demanding appropriate vision assessment to pick up coexisting CI in children with learning difficulties.

The binocular vision anomalies and normative data (BAND) study (Hussaindeen et al., 2015, 2016a) is an epidemiological study carried out in Tamilnadu with the objectives of estimating normative data of BV parameters and to estimate the prevalence of NSBVA. The CISS and ABS was administered to all children as part of the initial vision screening process in the BAND study, to understand the vision related quality of life (VR-QOL).

The comprehension of CISS and ABS in a community set-up in our ethnicity needed to be explored. In an earlier hospital based study done on adults as part of this study, the CISS validity was questionable. The results of this study is given in chapter 8. But as CISS is primarily used in the community by the CITT study group for the diagnosis of CI, we aimed to understand the utility of CISS and ABS in a communitybased set-up in all types of NSBVA, not just restricting to CI. The items in the CISS though specific to CI could also be applied to other NSBVA due to the overlapping symptoms and this study intended to test the same.

9.2 METHODS

The detailed methodology of BAND study is briefed in chapter 2. As part of the initial screening process, the CISS was self-administered to children above 8 years of age and the ABS was filled through the respective class teachers for the entire sample. The CISS and ABS questionnaires are provided in the Appendices 4 and 5.

The academic achievement report for every child is obtained from the school administration for the latest exam conducted. Certain schools had mark based performance whereas others had grade-based performance. The scores and the grades were transformed to their appropriate percentages for analysis for all subjects for uniformity.

9.3 RESULTS

The demographics of the population are shown in Table 4.2. For the CISS and ABS scores analysis, data from the rural and urban were clubbed and the data was analyzed to look for the pattern in the overall sample and to assess difference between children with NSBVA and NBV. The analysis was done for valid, completely filled questionnaires. As CISS was administered for children above 8 years of age, comparison between CISS vs. ABS and CISS vs. academic performance was restricted to age group of 8 and above. In the overall sample, statistically significant association was seen between academic performance scores and ABS scores (Chi-square, $p < 0.001$). Lower academic performance scores were associated with higher ABS scores (Spearman's $r = -0.4$, $p < 0.001$). Similarly, significant association was seen between academic performance scores and CISS (Chi-square, $p < 0.001$). Lower academic performance scores were associated with higher

CISS scores (Spearman's $r = -0.2$, $p < 0.001$). Between ABS and CISS scores, statistically significant association was observed (Chi-square, $P < 0.001$), and a weak positive correlation was seen (Spearman's $r = 0.1$, $p < 0.05$) with the pattern of higher ABS scores in children with higher CISS scores.

Between NBV and NSBVA, except for the CISS scores, both the ABS and academic performance scores did not reach statistical significance (Mann–Whitney U test, $p > 0.05$) (Table 9.1). Among NSBVA, CI, and AIF had the highest prevalence of 16% and 10.1% respectively. Hence, the ABS, CISS, and the academic performance scores were analyzed to look for difference between these two NSBVA, and showed statistical insignificance (Mann–Whitney U test, $p > 0.05$) (Table 9.2).

9.4 DISCUSSION

The BAND study in a large cohort of 920 children assessed the prevalence of NSBVA among the rural and urban school children. We administered the CISS to the students and ABS to the teachers, while the academic performance report was collected from the school administration. The ABS is a 6-item survey that evaluates parents' concern about school performance and perceptions of the frequency of visual problems such as

TABLE 9.1 Comparison of CISS, ABS, and academic performance scores between NBV and NSBVA

	Normal binocular vision (NBV)	**Non-strabismic binocular vision anomaly (NSBVA)**	**Mann–Whitney U test (p-value)**
Mean (SD) age	12 (2.8)	12.7 (2.7)	<0.05*
CISS (median, IQR)	4 (1–8) N = 424	7 (3–13) N = 175	<0.05
ABS (median, IQR)	7 (0–10) N = 637	7 (0–12) N = 283	>0.05
Academic performance (median, IQR)	80 (70–90) N = 511	80 (70–90) N = 218	>0.05

*Un-paired *t*-test.

TABLE 9.2 Comparison of CISS, ABS, and academic performance scores between CI and AIF

BV parameters	Convergence insufficiency (CI)	Accommodative infacility (AIF)	Mann–Whitney U test (p-value)
Mean (SD) age (in years)	12.7 (2.7)	12.6 (2.6)	>0.05*
CISS (median, IQR)	8 (3–15.75) N = 141	5 (3–11) N = 78	>0.05
ABS (median, IQR)	8 (1.5–12) N = 96	6 (0–11.5) N = 59	>0.05
Academic performance (Median, IQR)	80 (70–80) N = 117	80 (70–80) N = 78	>0.05

*Un-paired *t*-test

difficulty completing homework, avoidance, and inattention while reading or performing close work (Rouse et al, 2009).

In our study, in the overall sample, there was a significant association between ABS, academic performance scores and CISS (Chi-square p<0.05). Children who had lower academic performance grades scored higher in the CISS and ABS, revealing that children with low level of visual symptoms have better academic performance. But when children were categorized into NSBVA and NBV, we did not find any significant difference in scores in ABS (median score: 7 for both NBV and NSBVA), CISS (median score: NBV: 4; NSBVA: 7) and academic grades (median score: 80% for both NBV and NSBVA). In the CITT study (Rouse et al, 2009) in a sample of 212 children with symptomatic CI and 49 children with normal binocular vision aged 9–17 years, children with CI and parental report of attention deficit hyperactivity disorder (ADHD) scored higher on the ABS (mean score: 15.6) compared to children with NBV (mean score: 8.7). It is a limitation of the study that the ADHD was not from a professional diagnosis perspective, but parent based. The CITT study group (Rouse et al., 2009) did not include the actual academic performance grades of the children in the analysis. Thus performance on ABS could not directly be extrapolated to academic performance in real life.

In our study, we designed the study such that ABS was administered to class teachers. It is agreed that the ABS is designed to be administered to parent, but in a large population-based study like this, getting the questionnaire filled from the parent has logical constraints. The teachers as well cannot be burdened with this task of collecting the questionnaires back from the parents for the same reason of loss of the questionnaire as mentioned above. The response rate for the questionnaire was 79.2% from the teachers, and in a public school set-up, the response from parents would be even lesser. Hence we adopted this strategy of teacher reported ABS scores and thus the scores are based on the understanding of teachers' perspective about the visual performance of children in the classroom set-up. Based on our results, we were not able to conclude about the association between NSBVA and academic performance.

The second part of the study focused at understanding the visual symptoms of children with NSBVA using the CISS. In this study, significant association was seen between academic performance scores and CISS such that lower academic performance scores were associated with higher CISS scores in the overall sample. Similarly, significant positive correlation as observed between ABS vs. CISS that higher ABS scores in children was related to higher CISS scores. This shows that academic performance is influenced by visual behavior. But when the sample was classified into NSBVA and NBV, we did not find any significant difference in the CISS scores between the two groups. This could have been observed due to various reasons. Firstly, the comprehension of the CISS in itself could limit the interpretation of the results. The response rate of children to CISS was 90% (789 out of 873 children aged between 8–17 years responded to the survey). Rest of the children had significant difficulty comprehending the questionnaire. Next is the interpretation of the items in the CISS. Based on our parallel study in a hospital-based population aged 9–35 years, we found that, majority of clinically diagnosed symptomatic CI (48.9%) passed the CISS, according to the cut-off provided by the CITT study group (unpublished data). This demands the need for validation of the CISS in our ethnicity prior to interpreting the results in the context of its comprehension and association with visual symptoms.

Due to the high prevalence of CI and AIF in this population (Hussaindeen et al, 2016 b), we also looked at the difference in VR-QOL scores between this vergence vs. accommodative anomaly. The difference was not statistically significant, revealing that the symptom levels are not different between the two NSBVA and its association with academic performance remains equivocal.

One limitation that could have potentially influenced the results is the academic achievement of our population. The median academic performance percentage is 80%, showing that most of our subjects are academic achievers. Only a very less percentage (2.3%) of the sample were below average performance (less than 40%), and this limits the understanding of its association with VR-QOL scores. But it is also important to note that, this is the realistic trend that would be encountered in any school set-up with lowest fail rates policy.

Through this study, we conclude that, using the CISS and ABS, no significant difference was established between academic performance and visual symptoms between NSBVA and NBV. Children who tend to have low level of symptoms and lesser concerns with visual performance during academic activities tend to perform better in school exams. Thus understanding visual performance in school children becomes important to understand the VR-QOL. Better VR-QOL tools customized and validated for the particular ethnicity are valuable in such circumstances.

CHAPTER 10

GENERAL SUMMARY AND RECOMMENDATIONS

The objectives of the binocular vision anomalies and normative data (BAND) project are four fold.

- To determine normative data of binocular vision parameters among school children
- To estimate the prevalence of binocular vision (BV) anomalies among school children in rural and urban Tamilnadu
- To arrive at the minimum test battery needed to pick up binocular vision anomalies in a community set up &
- To provide vision therapy to children identified to have binocular vision anomalies and to assess the impact of vision therapy on quality of life and reading performance after vision therapy
- Also as part of this study, estimating the prevalence of convergence insufficiency and understanding the utility of the CISS in the hospital based set-up was also carried out.

10.1 KEY FINDINGS

- The normative data for vergence and accommodative parameters for the Indian children between 7 and 17 years of age are reported. The developmental trend of accommodation and vergence differences and significant differences in cut-off between the current data and available literature are reported (Table 3.4).
- Non-strabismic binocular vision anomalies are highly prevalent among school children (30.8%) in both the rural and urban areas. Convergence insufficiency is the most common (16%) followed by accommodative infacility (AIF) (10%) in both the rural and urban population. Screening for binocular vision anomalies should be part

of the vision screening protocol and appropriate intervention should be planned for the binocular vision anomalies.

- The prevalence of convergence insufficiency based on standard clinical criteria for diagnosis is 28.5% in a hospital-based population in the Indian ethnicity.
- From the current study, significant correlation is established between academic performance and VR-QOL; however, association between academic performance and the presence of a NSBVA is inconclusive.
- The convergence insufficiency symptom survey (CISS) needs validation and modification due to comprehension issues in the Indian population.
- Innovative delivery models of vision therapy as proposed in the BAND study is a feasible and viable model to combat visual morbidity due to the high prevalence of NSBVA in the community.
- The minimum test battery of difference between distance and near phoria, monocular accommodative facility and NPC-PL yield good sensitivity and specificity for diagnosis of NSBVA in a community set-up. NPC with penlight and red filter (break >10 cm) can be a standalone test to diagnose CI and monocular accommodative facility with ±2.00 DS accommodative flippers (<7 CPM) can be a standalone test to diagnose AIF in the community set-up.

10.2 RECOMMENDATIONS

The future scope of the study is to incorporate screening for BV anomalies as a routine in school vision screening program. Advocacy for the same will be carried out through awareness sessions and educational materials to patient and practitioner. The normative data for binocular vision parameters would be extended to age group beyond age 17 so as to understand the changes in BV parameters longitudinally in a cross-sectional cohort. Also prevalence estimates in the higher age group need to be understood. Vision-related quality of tools such as the CISS and ABS demand validation and modification and this will be carried out in our ethnicity. Innovative delivery models and tools for vision therapy in a community set-up will be further explored.

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APPENDICES

APPENDIX 1
MANUAL OF PROCEDURES

(Adopted and modified from the convergence insufficiency treatment trial (CITT; Scheiman et al, 2005))

The binocular vision test procedures for NPC, NPA, accommodative facility, cover test, NFV, and PFV were adopted from the convergence insufficiency treatment trial protocol.

COVER TESTING: ALTERNATE COVER TEST (ACT)

Testing Protocol

1. Select an isolated letter 20/30 at 6 m.
2. Perform testing through subject's optical correction if applicable.
3. Use the Gulden B-16 prism bar that is free of scratches that may interfere with the patient's ability to see the target.
4. Instruct the subject to fixate the letter and to "keep it clear" throughout testing.
5. Cover the subject's right eye (OD) and watch left eye (OS) as OD is covered.
6. Cover the subject's OS and watch OD as OS is covered.
7. Allow the subject adequate time to regain fixation.
8. Neutralize the ACT according to the following procedure:
   a. Introduce prism with the base in the appropriate direction.
   b. Cover one eye with the occluder, interposing the prism behind the occluder.
   c. Switch the occluder and observe the eye movement behind the prism.
   d. Interpose different magnitudes of prism until neutrality is obtained.
   e. Continue adding prism until the first reversal (subject was initially exo and now becomes eso through the prism). The amount of prism that resulted in neutrality before this reversal of movement is recorded as the high neutral value.

9. Record the amount and base of prism for the high neutral.
10. Repeat the procedure at 40 cm using a single 20/30 letter.
11. During the cover test procedure the examiner should also observe whether a vertical deviation is present.
    a. If a vertical deviation is present, the examiner should measure the magnitude of the deviation and record.

BINOCULAR VISION TESTS

MODIFIED THORINGTON TEST

Testing Protocol

i. Make sure that the room is moderately illuminated to ensure the visibility of the red line produced by the Maddox rod.
ii. Begin testing with subject wearing his/her optical Rx.
iii. Ask the subject to wear the trial frame with the Maddox rod in front of the right eye with streaks oriented horizontally for the horizontal deviation and vice versa for the vertical deviation.
iv. The subject is asked to report the number on the card along with the direction (Center, right or left, up or down) at which the red streak coincides.
v. The corresponding number along with the direction is noted down as the deviation
vi. For example, if the streak coincides with number 3 on the right side of the chart, a 3 esophoria is noted down as the horizontal heterophoria

NEAR POINT OF CONVERGENCE (NPC)

Testing Protocol

1. Make sure that ambient room illumination is present.
2. Begin testing with subject wearing his/her optical Rx is applicable
3. Use the Astron International (ACR/21) Accommodative Rule with the printed Gulden fixation target consisting of a single column of 20/30 letters at 40 cm.

4. Hold the edge of rule on the center of the subject's forehead just above the level of his/her brow (so the patient is looking down slightly at the target). Begin with the target placed at the 40 cm mark on the rule.
5. Instruct subject "to look at letters and report when they become double or break into two but try to keep the target one/single as long as possible."
6. Slowly (1-2°cm/sec) move target toward subject. When diplopia is reported stop moving the target and ask the subject "Does it stay two or does it come back into one?"
   - If it comes back into one within 1-2 seconds, continue slowly moving the target towards the patient until the patient is unable to regain fusion. Do not hold the target in place for longer than 2 seconds.
   - If it stays double, this endpoint is the NPC break.
   - If the examiner observes a loss of fusion, without a subjective report of double, the point at which the examiner observed a loss of fusion is considered the objective NPC break.
   - If the patient continues to converge until the target is against the nose/brow (i.e. break does not occur), measure how closely the subject converged and consider this the NPC break.
7. Measure the NPC break to the nearest half centimeter (using the center of the subject's forehead just above the level of the brow as the zero measure point from which the NPC is taken.)
8. After the break point is note, ask the subject to tell you "when it comes back together into one" and slowly move the target away from the subject until the subject reports single vision or the examiner observes a recovery of fusion. This is the NPC recovery.
9. Measure the NPC recovery to the nearest half centimeter.
10. Record the NPC break and recovery values on the appropriate data form.
11. Measure the break and recovery as described above three times, waiting 10 seconds between paired break/recovery measurements.
12. If the break point is not appreciated until the tip of the nose, the break and recovery point is noted as 1 cm.

NEGATIVE FUSIONAL VERGENCE (NFV)

Testing Protocol

1. Make sure that ambient room illumination is present.
2. Ensure that prisms are clean and that there are no scratches that may interfere with the patient's ability to see the target.
3. Begin testing with subject wearing his/her optical Rx.
4. Direct the subject's attention to the vertical row of 6/9 reduced snellen letters fixed on the wall at 3 meters.
5. Place Gulden B-16 horizontal prism bar with the flat side of the prism bar towards the subject in a base-in orientation with subject viewing through 1Δ BI.
6. Ask the subject to "tell me when the letters become blurred or become double (split into 2), but try to keep the target single as long as possible" as BI prism is introduced.
7. Increase magnitude of BI prism at approx 2Δ/sec, pausing at each prism to confirm that the target is "single and clear."
8. If the subject reports blur, pause and note BI prism amount then continue to increase BI prism pausing at each prism to confirm that the target is "single." When the subject reports double or break, ask subject "Does it stay two or does it come back into one?" Continue to introduce BI prism if subject recovers single vision. When subject can no longer maintain single vision and has diplopia, note the BI prism amount and record this value at the "BI break."
9. After the subject reports diplopia, increase the BI prism by 5Δ, and then at a rate of about 2Δ /second, reduce the BI prism until the subject reports single vision. Consider this the "recovery" finding. If recovery finding is higher than the break, the examiner should repeat the entire measurement (blur, break and recovery).
10. Accurately record blur, break and recovery findings in the appropriate places on the data collection form.
11. Repeat blur/break/recovery sequence once more waiting 30 seconds between measures.
12. Repeat the same procedure for near.

13. Place target (Gulden Fixation Stick with single column of 20/30 letters) in primary gaze 40 cm from subject's eyes.
14. Repeat steps 5–12

POSITIVE FUSIONAL VERGENCE (PFV)

PFV should be performed after the negative fusional vergence (NFV) assessment. The examiner should wait 30 seconds after the NFV measure before performing the PFV measures.

Testing Protocol

1. Make sure that ambient room illumination is present.
2. Ensure that prisms are clean and that there are no scratches that may interfere with the patient's ability to see the target.
3. Begin testing with subject wearing his/her optical Rx.
4. Direct the subject's attention to the vertical row of 6/9 reduced snellen letters fixed on the wall at 3 meters.
5. Place Gulden B-16 horizontal prism bar with the flat side of the prism bar towards the subject in a base-out orientation with subject viewing through 1Δ BO.
6. Ask subject to "tell me when the letters become blurred or become double (split into 2), but try to keep the target single as long as possible" as BO prism is introduced.
7. Increase magnitude of BO prism at approx 2Δ/sec, pausing at each prism to confirm that the target is "single and clear."
8. If the subject reports blur, pause and note BO prism amount then continue to increase BO prism pausing at each prism to confirm that the target is "single." When the subject reports double or break, ask subject "Does it stay two or does it come back into one?" Continue to introduce BO prism if subject recovers single vision. When subject can no longer maintain single vision and has diplopia, note the BO prism amount and record this value as the "BO break."
9. After the subject reports diplopia, increase the BO prism by 5Δ, and then at a rate of about 2Δ/second, reduce the BO prism until the subject reports single vision. Consider

this the "recovery" finding. If recovery finding is higher than the break, the examiner should repeat the entire measurement (blur, break and recovery).

10. Accurately record blur, break and recovery findings in the appropriate places on the data collection form.
11. Repeat blur/break/recovery sequence once again waiting 30 seconds between measures.
12. Repeat the same procedure for near.
13. Place target (Gulden Fixation Stick with single column of 20/30 letters) in primary gaze 40 cm from subject's eyes.
14. Repeat steps 5–12

NOTE: If diplopia is not reported but examiner notes loss of fusion, the prism through which fusion is lost will be recorded as the "break" finding. Likewise, an examiner observation or recovery of fusion will be recorded as "recovery."

NOTE: If the patient is able to fuse the largest (45Δ) prism, record 45Δ for the break value and have the patient close or cover one eye to break fusion so that recovery can be measured. Record the amount of prism through which the patient was able to regain fusion (maximum value would be 45Δ).

VERGENCE FACILITY

Testing Protocol

1. Make sure that ambient room illumination is present.
2. Ensure that prisms are clean and that there are no scratches that may interfere with the patient's ability to see the target.
3. Begin testing with subject wearing his/her optical Rx.
4. Direct the subject's attention to the vertical row of 6/9 reduced snellen letters in the near Gulden stick.
5. Place the Vergence flippers with base in direction in front of the eyes
6. Ask subject to "tell me IF the letters remain single, and if becomes double try to make the target single and let me know" as BI prism is introduced.

7. Flip the prisms to the Base outside with the same instructions
8. Count the number of flips made in a minute
9. If patient is unable to fuse the letters on any of the sides even with effort at the end of 1 minute, documents as "Fails BO or BI" depending on the direction of difficulty and terminate the test

AMPLITUDE OF ACCOMMODATION

Testing Protocol

1. Begin testing with the subject wearing his/her optical Rx.
2. Occlude the subject's left eye.
3. Hold the Astron Accommodative Rule (with the printed Gulden fixation target consisting of a column of 20/30 letters at 40 cm) gently with edge of rule above subject's right eye just above the level of his/her brow. Begin with the target placed at the 40 cm mark on the rule.
4. Instruct the subject to, "Tell me when the letters first start to blur, but try to keep the letters clear as long as possible."
5. Slowly move the target toward the subject at approximately 1 to 2 cm/sec until subject reports first blur. Ask if the letters stay blurry or become clear. If target becomes clear, continue moving target closer until blurred. Stop at "first sustained blur."
6. End the test when "first sustained blur" is reported.
7. Measure to the nearest one-half centimeter (using forehead just above the level of the subject's brow as the zero measure point).
8. The test is repeated for the left eye with the right eye occluded and finally for both the eyes together.

ACCOMMODATIVE FACILITY

Testing Protocol

1. Ensure that the ±2.00 DS lens flippers are clean and that there are no scratches that may interfere with the patient's ability to see the target.

2. Perform testing with subject wearing his/her optical Rx.
3. Occlude the subject's left eye.
4. Have subject view the 20/30 letters on the word rock card grid
5. Place plus side of lens flipper before subject's right eye. Ask subject to try to make letters clear as quickly as possible.
6. Instruct subject to report clarity (say "clear") as soon as the letters are clear.
7. When letters are reported to be clear, quickly flip the flipper to the minus side, again instructing subject to read the next letter& report when clear.
8. Prepare to begin timing for one minute using a stopwatch.
9. Start timing as you place the plus side of the flipper lens in front of the subject's eye. Continue to alternate sides of flipper lenses for 1 minute, while counting the number of "words" that the subject was able to clear.
10. Record number of words on data collection form.

NOTE: Even if the subject has difficulty (i.e., is slow or takes a while) clearing a lens, testing should be continued for a full minute. However, if the subject cannot clear one side of the flipper lens in one minute, then 0 flips will be recorded. The lenses should be "flipped" from one side to another, not slid/moved up and down in front of the subject's eye.

APPENDIX 2

DIAGNOSTIC CRITERIA FOR NSBVA

This was the generic criteria followed for the diagnosis of NSBVA. The quantitative details for the BV parameters were later fit into the criteria after the normative data was collected. These quantitative parameters included

1. Magnitude of distance and near phoria
2. NFV and PFV amplitudes for distance and near
3. Criteria for accommodative facility and vergence facility in cycles per minute
4. Lag of accommodation in MEM
5. Normative accommodative amplitudes (Mean ±1.00 SD)

1. CONVERGENCE INSUFFICIENCY (CI)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, intermittent diplopia.

Signs:

1. Greater exophoria for near than distance
2. Receded NPC (near point of Convergence) break with accommodative target >6 cm
3. Difficulty with base out prisms/reduced PFV (positive fusional vergence) (or) failing Sheard's criteria (PFV less than twice the near phoria)
4. Difficulty clearing +2.00 DS with binocular accommodative facility

2. DIVERGENCE INSUFFICIENCY (DI)

Symptoms: Associated with distance viewing. The most common includes intermittent diplopia for distance, headache, and eyestrain.

Signs:

1. Esophoria greater for distance than near, by any magnitude
2. Difficulty with base in prisms/low NFV (negative fusional vergence) for distance
3. Difficulty clearing –2.00 DS with binocular accommodative facility

3. CONVERGENCE EXCESS (CE)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common includes asthenopia and headaches, intermittent diplopia.

Signs:

1. Esophoria greater at near than distance
2. Difficulty with base in prisms/ reduced negative fusional vergence at near
3. Difficulty with binocular accommodative facility with –2.00 DS
4. High MEM lag of accommodation

4. DIVERGENCE EXCESS (DE)

Symptoms: Associated with distance viewing than near. The most common includes intermittent diplopia for distance, headache, and eyestrain.

Signs:

1. Intermittent to constant exo deviation for distance greater than near
2. Difficulty with Base out prisms/ Low PFV for distance
3. Difficulty clearing +2.00 DS with binocular accommodative facility

5. FUSIONAL VERGENCE DYSFUNCTION (FVD)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, blurred vision and difficulty concentrating on near visual tasks.

Signs:

1. Reduced NFV and PFV for near and distance
2. Difficulty with both ±2.00 DS in binocular accommodative facility

6. BASIC ESOPHORIA

Symptoms: Associated with reading or other near tasks and with distant activities. The most common near point complaints include eyestrain, headaches and blurred vision. Common symptoms associated with distance includes blurred vision and diplopia when watching television and in classroom.

Signs:

1. Equal amount of esophoria at distance and near
2. Reduced negative fusional vergence at distance and near
3. Difficulty with binocular accommodative facility with –2.00 DS

7. BASIC EXOPHORIA

Symptoms: Associated with reading or other near tasks and with near and distant activities. The most common near point complaints include eyestrain, headaches, and blurred vision.

Signs:

1. Equal amount of exophoria at distance and near
2. Receded NPC with accommodative target
3. Reduced PFV for both distance and near
4. Difficulty clearing +2.00 DS with binocular accommodative facility

8. ACCOMMODATIVE INSUFFICIENCY (AI)

Symptoms: Blurred near vision, discomfort and strain associated with near tasks, fatigue associated with near point tasks, difficulty with attention and concentration when reading.

Signs:

1. Reduced amplitude of accommodation compared to the expected normal amplitudes for age as per the normative data
2. Blur at near point testing at Harmon's distance
3. Difficulty with monocular and binocular accommodative facility with - 2.00 DS
4. High MEM lag of accommodation

9. ACCOMMODATIVE EXCESS (AE)

Symptoms: Blurred distance vision worse after reading or other close work and often worse toward the end of the day, headaches and eyestrain after short periods of reading, difficulty focusing from far to near, sensitivity to light

Signs:

1. Low MEM finding (lead of accommodation)
2. Difficulty clearing +2.00 DS with monocular and binocular accommodative facility
3. Presence or absence of near Esophoria

10. ACCOMMODATIVE INFACILITY (AIF)

Symptoms: Blurred near vision, blurred distance vision after near visual tasks and vice versa, delayed focusing of objects, discomfort and strain associated with near tasks, fatigue associated with near tasks, difficulty with attention, and concentration when reading.

Signs:

1. Difficulty with monocular/ binocular accommodative facility with ±2.00 DS
2. Secondary reduction in fusional vergence amplitudes, both NFV and PFV
3. Difficulty with both BO and BI prisms in vergence facility testing

APPENDIX 3

DIAGNOSTIC CRITERIA FOR NSBVA DERIVED FROM THE BAND STUDY

The generic criteria for the diagnosis is adopted from Scheiman & Wick and the specific cut-off has been derived from the normative data from the phase one of the current study.

1. CONVERGENCE INSUFFICIENCY (CI)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, intermittent diplopia.

Signs:

1. Greater exophoria for near than distance by >2 PD
2. Receded near point of Convergence (NPC) break with accommodative target >6 cm
3. Receded NPC break with pen light and red filter >12 cm
4. Reduced Positive fusional vergence (PFV) break <15 PD
5. Difficulty clearing +2.00 DS with binocular accommodative facility (BAF) –<8 CPM

For diagnosis: Two out of the first four criteria is mandatory

2. DIVERGENCE INSUFFICIENCY (DI)

Symptoms: Associated with distance viewing. The most common includes intermittent diplopia for distance, headache, and eyestrain.

Signs:

1. Esophoria greater for distance than near >3 PD
2. Reduced NFV (negative fusional vergence) break <6 PD for distance
3. Difficulty clearing –2.00 DS with BAF –<8 CPM

For diagnosis: Criteria 1 is mandatory with minimum one criteria from 2 and 3.

3. CONVERGENCE EXCESS (CE)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common includes asthenopia and headaches, intermittent diplopia.

Signs:

1. Esophoria greater at near than distance by 3 PD
2. Reduced NFV (negative fusional vergence) break <10 PD at near
3. Difficulty with BAF with –2.00 DS –<8 CPM
4. High MEM lag of accommodation > +1.25 DS

For diagnosis: Criteria 1 is mandatory with minimum one criteria from 2 -4.

4. DIVERGENCE EXCESS (DE)

Symptoms: Associated with distance viewing than near. The most common includes intermittent diplopia for distance, headache, and eyestrain

Signs:

1. Intermittent to constant exo deviation for distance greater than near >4 PD
2. Low PFV break <10 PD for distance
3. Difficulty clearing +2.00 DS with BAF –<8CPM

For diagnosis: Criteria 1 is mandatory with minimum one criteria from 2 and 3.

5. FUSIONAL VERGENCE DYSFUNCTION (FVD)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, blurred vision and difficulty concentrating on near visual tasks.

Signs:

1. Reduced NFV < 10 PD and PFV < 15 PD break at near and reduced NFV < 6 PD and PFV < 10 PD break at distance

2. Difficulty with both ± 2.00 DS in binocular accommodative facility –<8 CPM
3. Normal monocular accommodative facility (MAF) >8 CPM

For diagnosis: One out of the first two criteria is mandatory; Criteria 3 is mandatory

6. BASIC ESOPHORIA

Symptoms: Associated with reading or other near tasks and with distant activities. The most common near point complaints include eyestrain, headaches and blurred vision. Common symptoms associated with distance includes blurred vision and diplopia when watching television and in classroom.

Signs:

1. Equal magnitude of esophoria at distance and near
2. Reduced NFV break <6 PD at distance and <10 PD at near
3. Difficulty with BAF with –2.00 DS –<8 CPM

For diagnosis: Criteria 1 is mandatory with one out of the next 2 criteria

7. BASIC EXOPHORIA

Symptoms: Associated with reading or other near tasks and with near and distant activities. The most common near point complaints include eyestrain, headaches, and blurred vision.

Signs:

1. Equal amount of exophoria at distance and near
2. Receded NPC break <6 cm with accommodative target
3. Reduced PFV break <10 PD for distance and <15 PD at near
4. Difficulty clearing +2.00 DS with BAF –< 8 CPM

For diagnosis: Criteria 1 is mandatory with 2 out of the next 3 criteria

8. ACCOMMODATIVE INSUFFICIENCY (AI)

Symptoms: Blurred near vision, discomfort and strain associated with near tasks, fatigue associated with near point tasks, difficulty with attention and concentration when reading.

Signs:

1. Blur at near point testing at Harmon's distance
2. Reduced AA by 2 D or more from the average AA derived from the normative equation 16 – 0.3 (age)
3. Difficulty with MAF –< 7 CPM and BAF < 8 CPM with –2.00 DS
4. High MEM lag of accommodation (>+1.25 DS)

For diagnosis: Criteria 1 & 2 is mandatory with 1 out of the next 2 criteria

9. ACCOMMODATIVE EXCESS (AE)

Symptoms: Blurred distance vision worse after reading or other close work and often worse toward the end of the day, headaches and eyestrain after short periods of reading, difficulty focusing from far to near, sensitivity to light.

Signs:

1. Low MEM (lesser than or equal to Plano) (lead of accommodation)
2. Difficulty clearing +2.00 DS with MAF -< 7 CPM
3. Esophoria for near > 3 PD
4. Variable visual acuity findings
5. Variable static retinoscopy and subjective refraction

For diagnosis: Criteria 1 & 2 is mandatory with 1 out of the next 3 criteria

10. ACCOMMODATIVE INFACILITY (AIF)

Symptoms: Blurred near vision, blurred distance vision after near visual tasks and vice versa, delayed focusing of objects, discomfort and strain associated with near tasks, fatigue associated with near tasks, difficulty with attention and concentration when reading.

Signs:

1. Difficulty with MAF <7 CPM and/or BAF < 8 CPM with both ± 2.00 DS in the presence of normal fusional vergence findings
2. Normal amplitude of accommodation
3. Normal fusional vergence amplitudes

For diagnosis: All 3 criteria are mandatory

APPENDIX 4
CONVERGENCE INSUFFICIENCY SYMPTOM SURVEY (CISS)

Name:

Age: Gender: Male/ Female Grade:

Please answer the following question based on how your eyes feel after reading or doing any near work.

After each symptom listed, circle the number that best describes how often you experience that particular problem. 0 = never, 1 = (not very often) infrequently, 2 = sometimes, 3 = fairly often, 4 = always.

1.	Do your eyes feel tired when reading or doing close work?	0	1	2	3	4
2.	Do your eyes feel uncomfortable when reading or doing close work?	0	1	2	3	4
3.	Do you have headaches when reading or doing close work?	0	1	2	3	4
4.	Do you feel sleepy when reading or doing close work?	0	1	2	3	4
5.	Do you lose concentration when reading or doing close work?	0	1	2	3	4
6.	Do you have trouble remembering what you read?	0	1	2	3	4
7.	Do you have double vision when reading or doing close work?	0	1	2	3	4
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?	0	1	2	3	4
9.	Do you feel like you read slowly?	0	1	2	3	4
10.	Do your eyes ever hurt when reading or doing close work?	0	1	2	3	4
11.	Do your eyes feel sore when reading or doing close work?	0	1	2	3	4
12.	Do you feel "pulling" feeling around your eyes when reading or doing close work?	0	1	2	3	4
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?	0	1	2	3	4
14.	Do you lose your place while reading or doing close work?	0	1	2	3	4
15.	Do you have to reread the same line of words when reading?	0	1	2	3	4
	Total Score	___	___	___	___	___

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APPENDIX 5
ACADEMIC BEHAVIOUR SURVEY (ABS)

Name:

Age: Gender: Male/ Female Grade:

		Never	Infrequently	Sometimes	Fairly Often	Always
1.	How often does the child have difficulty completing assignments at school?					
2.	How often does the child have difficulty completing homework?					
3.	How often does the child avoid or say he/she does not want to do tasks that require reading or close work					
4.	How often does the child fail to give attention to details or make careless mistakes in schoolwork or homework?					
5.	How often does the child appear inattentive or easily distracted during reading or close work?					
6.	How often do you worry about the child's school performance?					

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2. Hussaindeen JR, Rakshit A, Neeraj K, George R, Swaminathan M, Kapur S, Scheiman M, Ramani KK. Normative data of Binocular vision parameters in Tamilnadu – Report 1 of Binocular Vision Anomalies and Normative Data (BAND) in Tamilnadu. Clin exp opto Oct 2016.
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2. **Hussaindeen J R**, George R, Swaminathan M, Suman Kapur, Krishna Kumar R: Binocular vision anomalies and Normative Data (BAND) study protocol and preliminary results, AAO annual meeting, November, 2014
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BRIEF BIOGRAPHY OF THE SUPERVISOR

Dr R Krishna Kumar, Principal of Elite school of Optometry did his Under-graduation, graduation and doctorate programmes in Optometry at the reputed Elite School of Optometry (ESO) run in collaboration with Birla Institute of Technology & Science, Pilani. He also possesses Fellowship in British Dispensing Optics (FBDO) and masters in psychology. He is working with Sankara Nethralaya & Elite School of Optometry for the past 23 years and has served as the head of the department of optometry at Sankara Nethralaya for almost a decade before his current tenure as principal of ESO. He has been the key person in the establishment of department of occupational optometry services of Sankara Nethralaya, started in the year 2012. He provides occupational optometry services to different industries (Watch repair, Agro Pulp Machinery, Jewellery making, Furniture manufacturer, Electronic manufacturer, Petro chemical and Iron & steel company) setting up vision standards and giving recommendations. He has many peer reviewed publications, and book chapters to his credit and also holds authorship for Dr. P.P. Santanam's Text book on occupational optometry, which serves as textbook in many optometry schools across India.

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BRIEF BIOGRAPHY OF THE CANDIDATE

Jameel Rizwana Hussaindeen has completed bachelors in Optometry from the Elite School of Optometry and is also the best outgoing researcher of the graduate program. Her graduate and doctoral research pertains to understanding binocular vision in children. She is a fellow of the American Academy of Optometry (AAO) and the College of Optometrists in Vision Development (COVD), USA. She is the recipient of Indo-US science and technology forum's scholarship for training on Infant vision at the Indiana University and also a recipient of the Endeavour-executive fellowship for training on eye movements at the University Of Melbourne, Australia. She currently heads the Binocular vision / Vision therapy clinic at Sankara Nethralaya (SN).

Article: Binocular Vision Anomalies and Normative Data (Band) In Tamilnadu – Study Design and Methods

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ABSTRACT

Purpose: To report the study design and methods of the "Binocular Vision Anomalies and Normative Data" (BAND) study in school children in Tamilnadu.

Methods: This is a cross-sectional study with an estimated sample size of 936 in rural and urban arms of Tamilnadu. A total of four schools with similar socio-economic factors have been selected in the rural and urban arm and children between 7 and 17 years of age are included based on simple random sampling. All children will undergo an initial screening protocol, followed by comprehensive binocular vision assessment. Children who are asymptomatic and who pass the comprehensive binocular vision assessment

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Keywords: accommodation, Binocular vision, convergence, Normative data, School screening

protocol will be included in the normative data study and children who fail the binocular vision assessment protocol will be included in the binocular vision prevalence study. Vision therapy will be provided to children with symptomatic BV anomalies and binocular vision assessment will be repeated after vision therapy. The primary objectives are to calculate prevalence estimates of binocular vision (BV) anomalies, and development of normative data. After the prevalence estimates are calculated, receiver operating characteristic (ROC) analyses will be performed for the binocular vision tests to find the tests that have the maximum sensitivity and specificity. After the ROC analyses, re-assessment of prevalence with the minimum test battery will be carried out.

Conclusion: This study is expected to provide the prevalence data for binocular vision anomalies in rural and urban Tamilnadu and normative data for binocular vision testing.

According to the American Optometric association (AOA) (1998),[1] diagnosis and treatment of binocular vision anomalies should be a priority aim for the pediatric population as accommodative and vergence dysfunctions can significantly impair the reading performance of a child especially after third grade due to the increasing visual demands.[2-5] Non-strabismic Binocular vision anomalies (NSBVA) were found to be more common among school children between 9 and 13 years.[3] Convergence insufficiency (CI) and accommodative insufficiency were common in school children between 8 and <15 years of age and these children were more symptomatic than the children in the normal binocular vision group.[6-8] According to a study by Borsting et al, 77.9% of children who are diagnosed with CI have accommodative insufficiency (AI) as the primary or co morbid cause; similarly 4.7% and 3.3% of elementary school children have AI as the primary diagnosis or co morbid cause respectively, resulting in increased symptoms.8 But most importantly, children may not realize that reading should be a comfortable experience. In addition, because non-strabismic binocular vision anomalies cannot be detected without clinical tests, parents and teachers are unable to determine if there is a vision problem just based on observation. Children with reading difficulties present with poorer accommodative facility, vergence facility, near point of convergence and accommodation and slower reading speed compared to age matched controls.[9] Appropriate spectacle prescription and vision therapy play a key role in the remediation of symptoms in these children.[10-12]

To the best of our knowledge, there are no prevalence data in the Indian literature for binocular vision anomalies. Hospital-based studies report varied frequencies of CI from 3.6% to 7.7%.[13-14] Among school children in Nepal, the reported prevalence of CI is 2.49%.[15] Recent Caucasian prevalence of non-strabismic binocular vision anomalies have been reported to be as high as 56.2% in the general adult population between 18-38 years[16] and 15.3% among University students.[17] Among children between 8 and 12 years reporting to a clinical set-up, definite CI has been reported to be 17.6% and the suspect categories comprise almost 50% of the sample.[6] Such high prevalence rates suggest the need for timely assessment, appropriate diagnosis, and management to improve the vision-related quality of life of these individuals.

A pre-requisite for classifying children as having normal or abnormal binocular vision, is the availability of normal mean values for the battery of different tests conducted as part of the binocular vision assessment.[18,19] In India, the diagnosis of binocular vision anomalies is currently based on the Caucasian normative values from Morgan et al (1944)[18] and Duane et al (1926).[20] Racial differences in binocular vision parameters have been reported in literature[21-23] and this suggests the need for Indian specific data. Hence, our objectives are to determine the prevalence of binocular vision anomalies among school children in rural and urban Tamilnadu along with the determination of normative data for binocular vision parameters in this population.

Estimates of binocular vision anomalies among school children will help in planning appropriate assessment and intervention. Moreover the normative data will have significant implications for the clinical practice and management of binocular vision anomalies.

Hence the objectives of this study are:

1. To estimate the prevalence of binocular vision anomalies among school children in rural and urban Tamilnadu
2. To collect normative binocular vision data of for school children
3. To arrive at the minimum test battery needed to pick up binocular vision anomalies in a community set up
4. To re-assess prevalence in the community to validate the minimum test battery

METHODOLOGY

This project has been approved by the Institutional Review Board of Vision Research Foundation (VRF) and follows the guidelines proposed by declarations of Helsinki. The study consisted of three phases.

Phase I: Training Program

Two optometrists who will participate in the study (AR, NK) will be trained and assessed for intra-examiner agreement with the principal investigator (JRH) of the study. The parameters of concern for the repeatability assessment include near point of convergence (NPC) with accommodative target, near point of accommodation (NPA), and distance and near fusional vergence amplitudes. The rest of the binocular vision tests are carried out by a single examiner at the study site. The repeatability cut-off for negative fusional vergence (NFV), positive fusional vergence (PFV), and NPC have been adopted from Rouse et al (2002).[24] Binocular vision assessment will be performed on 30 subjects and the Altman-Bland agreement will be determined. If the agreement for all the tests is not found to be within the clinically agreeable limits for test-retest variability, re-training will be given and the same process will be repeated.

Phase II. Epidemiological Field Work

The principal investigator presented the details of the project to the school administration and written informed consent has been obtained from the school authorities, along with oral consent from the parents. A meeting was organized to explain the project and procedures to the parents. An awareness session on common ocular diseases and binocular vision anomalies was presented to the students, and teachers.

The field work for the study began in February, 2014 and will be completed by December, 2015. The schools in rural and urban arms have been identified based on non-probability convenience sampling depending on acceptance from the school administration. After the sampling frame and sampling unit is identified, subject enrolment will be carried out based on simple random sampling.

Study Zones:

An area with a minimum population of approximately 5000, with a density of 400/square kilometre and 75% of the male population engaged in non-agricultural activities is termed as Urban and the rest of the areas are defined as Rural for the study, based on the Indian Census definition (1981).[25]

In rural arm, two schools have been identified in villages of Sricity (adjacent to Tiruvallur district, Tamilnadu) and in one village of Sankarankoil (Tirunelveli district) respectively. In the Urban arm, two schools have been identified in the Tambaram Municipality (Kanchipuram district).

Vision Screening and Eye Examination

The steps involved in the vision screening process are listed in Table 1 and the inclusion and exclusion criteria in Table 2.

Phase III A: Binocular Vision Screening Protocol

The pass criteria for the screening protocol[27] are:

Table 1: Steps in the vision screening

1.	Screening using a visual acuity cut-off of 6/9 using the ESO Pocket vision screener[26]
2.	Ocular motility using the Broad H test
3.	Pupillary assessment and torch light examination for gross ocular abnormalities
4.	Static retinoscopy and subjective acceptance using log MAR chart for children with refractive errors
5.	Stereo acuity for near using Randot stereo plates
6.	If a subject is found to have refractive error for the first time or if a change in refractive error of more than 0.50 D is detected during the refraction, glasses will be prescribed and binocular vision assessment will be done after 2 weeks of glass prescription. Tolerance limits for refractive errors were adopted from the CITT protocol (Scheiman et al, 2005)[10]
7.	Referral of children with strabismus, amblyopia and other ocular abnormalities to the base hospital
8.	After vision screening and eye examination is done, inclusion of subjects for prevalence data and normative data will be done based on the inclusion/ exclusion criteria.

1. Visual acuity better than or equal to 20/30 at distance and near
2. No symptoms of asthenopia, eyestrain, blurred vision, difficulty associated with reading
3. Stereo acuity > 100″ (Randot stereo test)
4. No constant or intermittent strabismus as detected using the cover test

No cut-off has been considered for NPC, accommodative amplitude, phoria and vergence parameters as the main outcome is to estimate normative data for these parameters in the asymptomatic children. Subjects who fail the screening criteria are considered to have binocular vision anomaly and subjects who pass the above mentioned criteria are included for the normative project. But this does not diagnose the subject to have normal BV, until they clear the comprehensive BV assessment. Asymptomatic subjects who does not report any difficulty during the BV assessment will be included for the normative data. There could be subjects who are asymptomatic and have a BV anomaly and there could be subjects who have low level of symptoms but still have normal BV.

Table 2: Inclusion and Exclusion criteria

Inclusion criteria	Exclusion criteria
Subjects in the age range of 7 and 17 years	Ocular abnormalities/ strabismus (constant and intermittent)
Best corrected visual acuity better than or equal to 6/9, N6	• History of any previous intraocular / squint surgeries • Self-reported history of ocular/head trauma • Self-reported h/o Juvenile diabetes

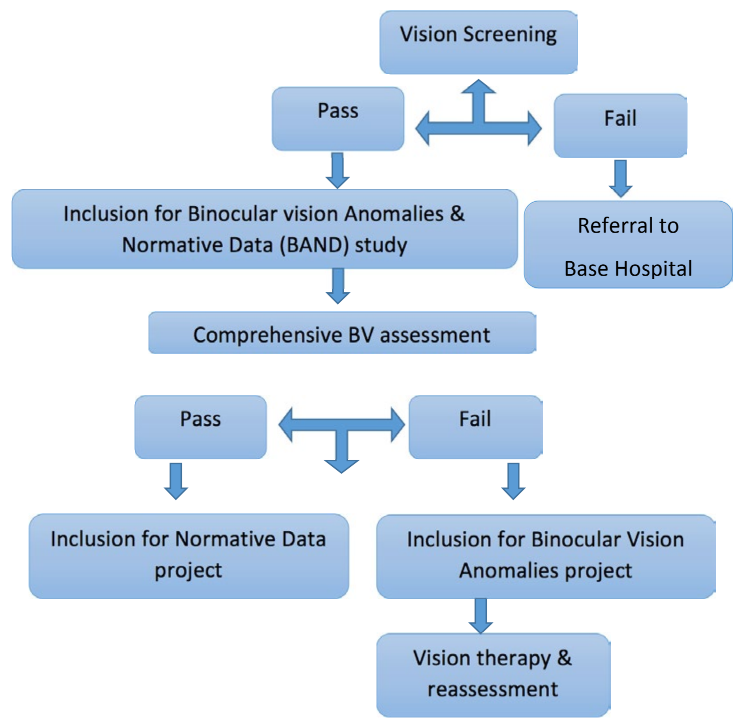

***Figure 1** Flowchart depicting the recruitment of subjects for the study*

This combination will be specifically looked for during the analyses and these subjects will be reassessed prior to classifying them to one of the two groups of normal BV versus NSBVA.

The flow of the recruitment of subjects is depicted in Figure 1.

Phase III B: Detailed Binocular Vision Assessment

The room where binocular vision assessment is done will be standardized for illumination levels (minimum of 480 Lux will be ensured) and a minimum length of 6 metres will be chosen to perform vision tests and binocular vision assessment for distance and near.

The outcome parameters in our study include the near point of convergence (NPC), phoria measures for distance and near, vergence amplitudes, vergence facility, Near point of accommodation (NPA), accommodative response, and accommodative facility.

Tests for Vergence

Different targets for *Near Point of Convergence* (NPC) testing have been reported in the literature. In our study, considering the age range to be tested, NPC will be assessed using two methods 1) an Astron International rule consisting of linear accommodative target of 6/9 reduced snellen letters and 2) using a penlight with red filter in front of right eye. The accommodative target procedure has been used extensively in the clinical set up and its reliability has been well established.[28] Penlight with red filter is considered to be a sensitive test in diagnosing CI as it tests for the maximum fusional ability of the subject eliminating the demand for accommodative convergence.[27-30] The measurements will be taken from the centre of the forehead as the Zero reference point. The break values are noted at a point when the patient reports doubling of images and the examiner also notes down objectively the deviation of one of the eyes when fusion is lost. Both the tests are repeated thrice and the average of the three measurements will be recorded as NPC. Both break and recovery values will be noted down. NPC maintained up to the center of the forehead will be given a value of 1 cm for analyses purposes.

Heterophoria testing is an important part of routine optometric testing and diagnostic in binocular vision testing. Presence of heterophoria and the magnitude of deviation will be assessed using the Modified Thorington test using a Bernell Muscle Imbalance Measure (MIM) card. Among the various different techniques available like Von-Graefe, Prism cover test, Maddox rod testing, etc, Modified Thorington (MT) method has been recommended by many authors[19,31-32] for its simplicity, control of accommodation and high reliability and repeatability.[32] Also this test is useful for children in whom measurement of phoria using prisms is difficult as this test eliminates the need for prism and thereby prism induced blur in one eye that could influence the accommodative demand of the target. The horizontal and the vertical deviation will be assessed at a distance of 3 m and 40 cm. The subject will be put with a trial frame with the Maddox rod oriented in the right eye horizontally and vertically for horizontal and vertical deviations respectively. The subject will be asked to report the position of the red streak on the horizontal and vertical numbers and the appropriate prism deviation will be noted down from the MIM card. If the red streak is reported out of the MIM card, or in case of unreliable responses, prism cover test will be done to assess the magnitude of heterophoria.

The calculated AC/A ratio will be calculated using the expression[33] AC/A = IPD + FD x (NP-FP) where IPD in centimetres, Near Fixation distance (FD) in metres, and near and far phoria (NP & FP) values in Prism Diopters are fed into the equation. IPD will be assessed using the Essilor® Pupillometer.

Fusional vergence amplitudes will be assessed using step vergence technique using a prism bar as it gives the advantage of objectively rechecking the end point for vergence based on the deviation of one of the eyes during testing.[19] For both near and far, the Negative fusional vergence (NFV) will be measured first followed by Positive fusional vergence to avoid influence of convergence testing on vergence recovery. Vertical row of letter of 6/9 Snellen equivalent will be used as the test stimuli and the prisms would be gradually increased in front of one eye until the subject reports diplopia (fusional vergence break) and then the amount of prisms are reduced until binocular single vision is restored (fusional recovery). The vergence testing will be done in free space without any chin rest or head support to mimic the natural testing conditions in the clinical set-up.

Apart from fusional vergence amplitudes, testing for *vergence facility* improves the sensitivity of diagnosis of binocular vision anomalies.[34] Vergence facility testing assess the dynamics of the fusional vergence system and a 12 Base out/ 3 Base in prisms combination has been found to differentiate the symptomatic from the normal BV group.[34] The flip prisms combination will be flipped from Base in to out and the subject will be asked to keep the vertical row of 6/9 letters clear and single. A practice session for 30 seconds is provided before the test is begun. One round of Base out and Base in will be counted as one cycle and the number of cycles per minute will be noted down. While the test is being done, the simultaneous vergence movement of the eyes will be noted down to ensure bifixation. If the bifixation movement is not noted along with nil appreciation of diplopia during testing, suppression is indicated and will be noted down.

Tests for Accommodation

The Near Point of Accommodation (NPA) is the most important parameter used in the diagnosis of accommodative anomalies. With respect to the measurements techniques, push-up technique, has been considered as a standard due to its robustness, where the near target equal to or one line better than the best corrected near visual acuity is moved closer to the eyes until a sustained blur is noted. The readings in metrics are converted to Diopters to arrive at the Near point of accommodation. Though this technique has problems of varying magnification of the target due to proximity, it has still been followed routinely in the clinical set-up. A modification suggested by Scheiman & Wick (2008)[19] to overcome this limitation include decreasing the near target size as it is taken closer to the patient's eyes. Because of the simplicity of administration and its use in the clinical set-up, the push-up test will be adopted for the study.

The near point card with 6/6 snellen equivalent word will be used as the target and will be brought closer to the right eye until the subject reports sustained blur. The Astron International rule centred on the forehead was used to measure the endpoint of blur. The test will be repeated binocularly; two measurements will be taken for both eye and the average of the two readings will be noted down in centimetres and then converted to its Dioptric equivalent.

Accommodative response refers to the response of the visual system to an accommodative stimulus and the difference between the stimulus and response is termed as lag or lead of accommodation. Physiologically, the response is less than the stimulus which is a purposeful error due to the depth of focus and steady state accommodation properties of the eye,[35] and the numerical value of the response is on the positive side defined as the lag of accommodation. If the response equals the stimulus, the numerical value of the response is zero; and if the accommodative response exceeds the stimulus, the numerical value is on the negative side defined as lead of accommodation. There are different techniques to estimate the accommodative response that include manual techniques such as Monocular Estimate Method (MEM) retinoscopy, Nott Retinoscopy and automated techniques such as using Open field autorefractor and Power refractor. MEM and Nott retinoscopy findings are comparable and less variable than the autorefractor accommodative responses.[36] MEM retinoscopy is widely practiced in the clinical setup due to its simplicity and ease to correlate with clinical findings.

The MEM retinoscopy will be performed on the right eye of all the subjects by quickly scanning across the horizontal meridian while the subject read the grade appropriate near reading material pasted on the retinoscope. As the child read the words aloud, appropriate lens powers will be quickly interposed until neutrality is observed. The lens powers used will be recorded accordingly.

Accommodative facility testing is gaining increasing evidence as a representation of the dynamics of the accommodative system. Plus and minus lenses of equal magnitude are interposed in front of the eyes and the visual system's response to relax and stimulate accommodation respectively are assessed. Reading material (Standard practice is the use of a word rock card consisting of letters of N10 and N8 font size) is used and the subject is asked to focus, keep the words clear and then read them as quickly as possible through plus and minus lenses alternately. The number of words read in one minute is noted down and the accommodative facility is calculated in cycles per minute where one cycle represents focusing through a plus and minus lens (accounting to two words for one cycle). Using +/-2.00 DS lenses at 40 cm is recommended for children to differentiate between symptomatic and symptomatic individuals[19] and use of amplitude scaled facility and suppression check are recommended as a standard testing approach in adults.[37-38] In our study, a 20/40 font size for 7-10 years and 20/30 font size for greater than 10 years will be utilized and the letters are chosen from their grade text books to ensure that language difficulty does not influence the test results. 40 three letter words are chosen and the word rock grid has been made. While the procedure is done, the subject will be given a practice session for 30 seconds before beginning the test to ensure familiarity of the task and to minimize learning effect. Monocular accommodative facility will be assessed in the right eye for all the subjects followed by binocular accommodative facility. In the pilot study before methodology was decided, binocular accommodative facility was tested used the Bernell No.9 vectogram using a Polaroid glasses as suppression check. This target was found to be difficult to comprehend in our sample and hence the word rock card will be utilized for binocular testing in this study. If suppression is revealed in other testing, then the binocular accommodative facility will not be performed and will be noted down as suppression.

Repetition of Tests

NPC is done thrice, NPA is done twice, vergence amplitudes are measured twice, MEM lag once and the accommodative and vergence facility are measured once (after a practice session for 30 seconds) and the average is taken for analyses.

Phase III C: VR-QOL Assessment

The Convergence insufficiency symptom survey (CISS) questionnaire[39] will be used to assess the severity of visual symptoms (15 items scored between 0 and 48 with greater scores indicating increasing symptoms associated with reading). The academic performance of each child would be obtained from their academic records and the Academic Behaviour survey (ABS) designed by Rouse et al (2009)[40] will be administered to the respective class teachers to score the child on their academic performance. This is done to understand the impact of non-strabismic binocular vision anomalies on academic performance of children. It is agreed that the ABS is designed to be administered to parents, but in a population based study like this, getting the questionnaire filled from the parents back poses risk of losing the questionnaire by the child and also difficulty to track the child again to get the questionnaire back. The teachers as well cannot be burdened with this task of collecting the questionnaires back from the students for the same reason of loss of the questionnaire as mentioned above.

Phase III D & E: Diagnosis of NSBVA

The normative data obtained from the study will be used to provide cut-off for the generic criteria adopted for the classification of NSBVA. This generic criteria[19] adopted for the diagnosis of NSBVA include conditions of convergence insufficiency, convergence excess, divergence insufficiency, divergence excess, basic esophoria, basic exophoria, accommodative insufficiency, accommodative excess, accommodative infacility and fusional vergence dysfunction. The prevalence of each specific type of NSBVA will be calculated. The cut-off for the generic criteria will be formulated after the normative data collection is over. Mean ± 1.00 SD will be used as the cut-off for the BV parameters.

Phase IV: ROC Analysis and Reassessment of Prevalence with the Minimum Test Battery

After the prevalence estimates are over, the ROC analyses will be performed to understand the minimum test battery needed to diagnose BV anomalies in a community set up.

After the ROC analyses, reassessment of prevalence will be carried out on 780 children chosen from a similar background as the phase 3 of the study. The prevalence estimates obtained from this phase will be compared with the earlier obtained prevalence to validate the minimum test battery.

Pilot Study to Determine Sample Size

Since there were no available data on prevalence of binocular vision anomalies in India, a pilot study was conducted on 100 children (15-18 years) in the urban location. The methodology for the pilot study was the same as the main study methodology detailed in the section below. The criteria and cut-off for the criteria for diagnosis of NSBVA was adopted from Scheiman & Wick, 2008.[19] From the pilot study, the prevalence of symptomatic NSBVA was found to be 46%. Based on this estimate, the sample size was estimated to be 780 at 95% confidence interval and 5% precision with a design effect of 2 for cluster sampling. Considering a 20 percentage loss to follow-up with the intervention arm, the calculated sample size was 936. Another pilot study was carried out on 31 children in two schools and modifications in methodology were made regarding selection of tests based on the understanding and literacy levels of the children.

PRELIMINARY RESULTS

The prevalence of Non-strabismic binocular vision anomalies in the pilot study (n=100) was 46%. The classification of categories of NSBVA is listed below (Table 3). The most prevalent NSBVA was convergence insufficiency (32% in the overall population and 69.5% among the NSBVA) followed by accommodative infacility (10% in the overall population 21.7% among the NSBVA).

Table 3: Prevalence of NSBVA – the pilot results

Category	N
Normal BV	54
NSBVA	46
Convergence Insufficiency	32
Convergence excess	3
Divergence excess	1
Accommodative infacility	10

Data Management

Descriptive statistics will be calculated for all the binocular vision parameters in the different age groups. Appropriate statistical tests will be utilized to assess the developmental trend of the parameters among the various age groups. The prevalence of binocular vision anomalies and the normative data for the BV parameters will be estimated and Receiver Operating Characteristic curves will be plotted to find the most sensitive tests for BV anomalies. After the reassessment, the prevalence of BV anomalies will be estimated again.

CONCLUSION

This study will provide the prevalence data of binocular vision anomalies in rural and urban Tamilnadu and also provide normative data that can be used to differentiate the pediatric population with normal binocular vision from children with binocular vision anomalies. The study will also provide insight into the differences in binocular vision parameters between ethnicities, and the minimum battery of tests needed to detect binocular vision anomalies in a community setting.

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Appendix 1
DIAGNOSTIC CRITERIA FOR NSBVA[19]

This is the generic criteria followed for the diagnosis of NSBVA. The quantitative details for the BV parameters will be fit into the criteria after the normative data is collected. These quantitative parameters include

1. Magnitude of distance and near phoria
2. NFV and PFV amplitudes for distance and near
3. Criteria for accommodative facility and vergence facility in cycles per minute
4. Lag of accommodation in MEM
5. Normative accommodative amplitudes (Mean +/-1.00 SD)

Any subject who fails more than 2 criteria will be diagnosed to have the specific anomaly.

1. CONVERGENCE INSUFFICIENCY (CI)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, intermittent diplopia.

Signs:

1. Greater exophoria for near than distance
2. Receded NPC (near point of Convergence) break with accommodative target > 6 cm
3. Difficulty with Base out prisms/ Reduced PFV (Positive fusional vergence) (or) Failing Sheard's Criteria (PFV less than twice the near phoria)
4. Difficulty clearing +2.00 DS with binocular accommodative facility

2. DIVERGENCE INSUFFICIENCY (DI)

Symptoms: Associated with distance viewing. The most common includes intermittent diplopia for distance, headache and eyestrain.

Signs:

1. Esophoria greater for distance than near, by any magnitude
2. Difficulty with base in prisms/ Low NFV (Negative fusional vergence) for distance
3. Difficulty clearing -2.00 DS with binocular accommodative facility

3. CONVERGENCE EXCESS (CE)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common includes asthenopia and headaches, intermittent diplopia.

Signs:

1. Esophoria greater at near than distance
2. Difficulty with base in prisms/ reduced negative fusional vergence at near
3. Difficulty with binocular accommodative facility with -2.00 DS
4. High MEM lag of accommodation

4. DIVERGENCE EXCESS (DE)

Symptoms: Associated with distance viewing than near. The most common includes intermittent diplopia for distance, headache and eyestrain

Signs:

1. Intermittent to constant exo deviation for distance greater than near
2. Difficulty with Base out prisms/ Low PFV for distance
3. Difficulty clearing +2.00 DS with binocular accommodative facility

5. FUSIONAL VERGENCE DYSFUNCTION (FVD)

Symptoms: Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, blurred vision and difficulty concentrating on near visual tasks.

Signs:

1. Reduced NFV and PFV for near and distance

2. Difficulty with both +/- 2.00 DS in binocular accommodative facility

6. BASIC ESOPHORIA

Symptoms: Associated with reading or other near tasks and with distant activities. The most common near point complaints include eyestrain, headaches and blurred vision. Common symptoms associated with distance includes blurred vision and diplopia when watching television and in classroom.

Signs:

1. Equal amount of esophoria at distance and near
2. Reduced negative fusional vergence at distance and near
3. Difficulty with binocular accommodative facility with -2.00 DS

7. BASIC EXOPHORIA

Symptoms: Associated with reading or other near tasks and with near and distant activities. The most common near point complaints include eyestrain, headaches and blurred vision.

Signs:

1. Equal amount of exophoria at distance and near
2. Receded NPC with accommodative target
3. Reduced PFV for both distance and near
4. Difficulty clearing +2.00 DS with binocular accommodative facility

8. ACCOMMODATIVE INSUFFICIENCY (AI)

Symptoms: Blurred near vision, discomfort and strain associated with near tasks, fatigue associated with near point tasks, difficulty with attention and concentration when reading.

Signs:

1. Reduced amplitude of accommodation compared to the expected normal amplitudes for age as per the normative data
2. Blur at near point testing at Harmon's distance
3. Difficulty with monocular and binocular accommodative facility with - 2.00 DS
4. High MEM lag of accommodation

9. ACCOMMODATIVE EXCESS (AE)

Symptoms: Blurred distance vision worse after reading or other close work and often worse toward the end of the day, headaches and eyestrain after short periods of reading, difficulty focusing from far to near, sensitivity to light.

Signs:

1. Low MEM finding (lead of accommodation)
2. Difficulty clearing +2.00 DS with monocular and binocular accommodative facility
3. Presence or absence of near Esophoria

10. ACCOMMODATIVE INFACILITY (AIF)

Symptoms: Blurred near vision, blurred distance vision after near visual tasks and vice versa, delayed focusing of objects, discomfort and strain associated with near tasks, fatigue associated with near tasks, difficulty with attention and concentration when reading.

Signs:

1. Difficulty with monocular/ binocular accommodative facility with +/- 2.00 DS
2. Secondary reduction in fusional vergence amplitudes, both NFV and PFV
3. Difficulty with both BO and BI prisms in Vergence facility testing

CLINICAL AND EXPERIMENTAL
OPTOMETRY

RESEARCH PAPER

Binocular vision anomalies and normative data (BAND) in Tamil Nadu: report 1

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Background: This population-based, cross-sectional study was designed to determine normative data for binocular vision and accommodative testing in rural and urban populations of Tamil Nadu.
Methods: A sample of 936 was determined, based on a previous pilot study. The epidemiological field work included a comprehensive eye examination and a binocular vision and accommodative assessment carried out in a total of four public schools, two each in the rural and urban arms of Chennai. An overall sample of 3,024 children between seven and 17 years of age was screened in the four schools and 920 children were included in the study.
Results: We found significant differences in expected values from the current clinical criteria for near point of convergence (NPC) with penlight, distance and near horizontal phorias, vergence facility, accommodation convergence/accommodation (AC/A) ratio, accommodative amplitudes, monocular and binocular accommodative facility (t-test: $p < 0.001$). The mean and standard deviation break/recovery values for NPC (in centimetres) with an accommodative target and penlight with red filter was $3 \pm 3/4 \pm 4$ and $7 \pm 5/10 \pm 7$, respectively. The mean accommodative amplitudes for the population could be estimated from the linear regression equation $16 - 0.3 \times$ (age). The vergence facility was 12 ± 4 cycles/minute and 14 ± 4 cycles/minute in the seven to 10 and 11 to 17 age groups, respectively. Monocular accommodative facility was 11 ± 4 cycles/minute and 14 ± 5 cycles/minute and binocular accommodative facility was 10 ± 4 cycles/minute and 14 ± 5 cycles/minute in the seven to 12 and 13 to 17 age groups, respectively. The mean calculated AC/A ratio was $5.4 \pm 0.6/1$.
Conclusion: The normative data for vergence and accommodative parameters for the Indian children between seven and 17 years of age are reported. The developmental trend of accommodation and vergence differences and significant differences in cut-off between the current data and available literature are reported. These differences have clinical implications for the interpretation, diagnosis and management of anomalies of binocular vision.

Key words: accommodation, binocular vision, convergence, normative data, school screening

Other than refractive anomalies, accommodative and binocular vision problems are the most common visual disorders in the clinical paediatric population.[1,2] These dysfunctions are termed under a broad umbrella 'non-strabismic binocular vision anomalies' (NSBVA) and the expected findings or normative data for binocular vision and accommodative testing used for the diagnosis and classification of NSBVA vary by ethnicity.[3–5] The most commonly used criteria are those reported by Morgan[6] and Scheiman and Wick.[7] One problem with these published norms is that they were developed primarily using adult subjects. In Morgan's study,[6] he states that 'the clinical data of some 800 subjects were analysed by statistical methods'. It does not state the ages of the subjects or even provide a mean age. Later in the paper, he states that all subjects had amplitudes of accommodation of at least 5.00 D and thus, the sample could be assumed to be less than 40 years of age. These issues suggest the need for a population-based study of the paediatric population in India to evaluate whether commonly used normative data established in the USA are applicable to children in India.

With the increasing prevalence of binocular vision anomalies in the paediatric population[8] and with the increasing complexity in near visual demands, timely diagnosis and appropriate management may enhance the vision-related quality of life of the paediatric population. In addition, to optimise the sensitivity and specificity of diagnosis, ethnicity-specific cut-off values for binocular vision parameters are mandatory.

The Binocular Vision Anomalies and Normative Data (BAND) study is designed to determine the expected values for binocular vision and accommodative testing in school children in rural and urban Tamil Nadu.

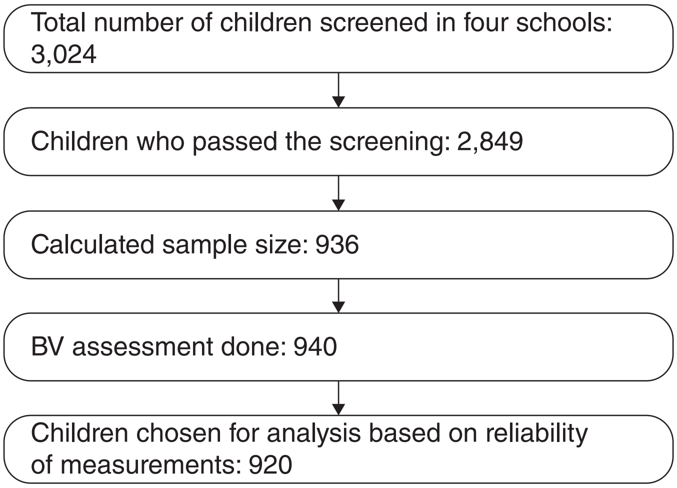

Figure 1. Flowchart of recruitment of subjects

METHODS

Full details of the BAND project methodology are available in a previous publication.[9] This research was approved by the institutional review board of the Vision Research Foundation and follows the guidelines proposed by the Declarations of Helsinki. We reviewed the study protocol with the school administration and written informed consent was obtained from the school authorities after obtaining oral consent from the parents. An oral assent was obtained from the children before the eye examination. A meeting was organised to explain the goals of the project and procedures to the parents. An awareness session about common ocular diseases and binocular vision anomalies was conducted with the students and teachers.

The field work for the study began in February 2014 and was completed by December, 2015. The schools in rural and urban locations were identified, based on non-probability convenience sampling and was dependent on acceptance from the school administration. After the sampling frame and sampling unit were identified, subject enrolment was carried out, based on simple random sampling.

In the rural location, two schools were identified in villages of Sricity (adjacent to Tiruvallur district, Tamil Nadu) and Sankarankoil (Tirunelveli district). In the urban location, two schools were identified in the Tambaram Municipality (Kanchipuram district).

Vision screening

The vision screening consisted of visual acuity testing using the Elite School of Optometry (ESO) pocket vision screener.[10] The ESO pocket vision screener has three rows of seven Sloan optotypes per line of 0.2 logMAR equivalent scaled for testing at three metres. This screener has 81 per cent sensitivity and 94 per cent specificity in screening for visual impairment. In addition, we performed versions, a pupillary assessment and a penlight examination for gross ocular abnormalities, static retinoscopy and subjective refraction using a logMAR chart for children with refractive errors and stereo-acuity at near using Randot stereo plates. If a subject was found to have a refractive error for the first time or if a change in refractive error of more than 0.50 D was detected during the refraction, glasses were prescribed and binocular vision assessment was repeated two weeks after wearing the eyeglass prescription. Tolerance limits for refractive errors were adopted from the Convergence Insufficiency Treatment Trial protocol.[4] Children with strabismus, amblyopia and other ocular abnormalities were referred to the base hospital.

After the vision screening was completed, inclusion of subjects for the normative data part of BAND was performed, based on the following inclusion/exclusion criteria. To be eligible for the next phase of the study children had to be seven to 17 years of age and have visual acuity better than or equal to 6/9, N6. The other pass criteria used for the screening protocol[11] at this phase were: no symptoms of asthenopia, eyestrain, blurred vision, difficulty associated with reading, stereo-acuity better than 100' (Randot stereo test) and no constant or intermittent strabismus. Children were also excluded if they had any previous intraocular/strabismus surgery, ocular/head trauma or juvenile diabetes. A total of 3,024 children underwent vision screening and 920 children were included, based on sample size calculation, and simple random sampling was done to include subjects in each age, based on the

Binocular vision/accommodative test	ANOVA	R^2 value	Age trend
Monocular accommodative amplitude	$p < 0.001$	0.79	7–10, 11–17
Binocular accommodative amplitude	$p < 0.001$	0.8	7–10, 11–17
Monocular accommodative facility	$p < 0.001$	0.5	7–11, 12–17
Binocular accommodative facility	$p < 0.001$	0.35	7–11, 12–17
Accommodation lag (MEM)	$p < 0.001$	0.01	7–12, 13–17
NPC break with AT	$p = 0.001$	0.015	Not found
NPC recovery with AT	$p < 0.001$	0.013	Not found
Distance PFV break	$p = 0.003$	0.02	Not found
Near NFV break	$p < 0.001$	0.67	Not found
Near NFV recovery	$p < 0.001$	0.82	7–12, 13–17
Near horizontal phoria	$p = 0.02$	0.02	Not found
Vergence facility	$p < 0.001$	0.84	7–11, 12–17

AT: accommodative target, MEM: monocular estimate method, NFV: negative fusional vergence, NPC: near point of convergence, PFV: positive fusional vergence.

Table 1. Developmental trend of binocular vision parameters

	Age group	
Accommodation parameters	**7–10**	**11–17**
Monocular AA (dioptres)	13 ± 3	11 ± 2
Binocular AA (dioptres)	13 ± 3	11 ± 3
	7–12	**13–17**
Monocular accommodative facility (cycles/minute)	11 ± 4	14 ± 5
Binocular accommodative facility (cycles/minute)	10 ± 4	14 ± 5
MEM accommodation lag (dioptres)	+0.4 ± 0.2	
Vergence parameters	**7–12**	**13–17**
Vergence facility (cycles/minute)	12 ± 4	14 ± 4
IPD (mm)	55 ± 3.3	59 ± 3
NPC with AT break (cm)	3 ± 3	
NPC with AT recovery (cm)	4 ± 4	
NPC with PL break (cm)	7 ± 5	
NPC with PL recovery (cm)	10 ± 7	
Near PFV break (prism dioptres)	26 ± 10	
Near PFV recovery (prism dioptres)	21 ± 10	
Near NFV break (prism dioptres)	15 ± 4	
Near NFV recovery (prism dioptres)	11 ± 4	
Distance PFV break (prism dioptres)	17 ± 8	
Distance PFV recovery (prism dioptres)	12 ± 7	
Distance NFV break (prism dioptres)	8 ± 2	
Distance NFV recovery (prism dioptres)	6 ± 2	
Distance horizontal phoria (prism dioptres)	0.02 ± 1	
Near horizontal phoria (prism dioptres)	–0.4 ± 2	
Distance vertical phoria (prism dioptres)	0 ± 0.5	
Near vertical phoria (prism dioptres)	0 ± 0.5	
Stereopsis (arc sec)	40 ± 15	
AC/A ratio	5.4 ± 0.6	

AA: amplitude of accommodation, AC/A: accommodation convergence to accommodation ratio, AT: accommodative target, IPD: inter-pupillary distance, MEM: monocular estimate method, NFV: negative fusional vergence, NPC: near point of convergence, PFV: positive fusional vergence, PL: penlight.

Table 2. Normative data for the Indian population for accommodation and vergence parameters from the BAND study

estimated sample size. The flowchart of recruitment is depicted in Figure 1.

Binocular vision assessment

Subjects who failed the screening criteria were referred for further management to the base hospital and subjects who passed were included in the study. Subjects who passed the screening protocol then underwent a comprehensive binocular vision assessment and were included in the BAND study.[9] Three examiners conducted all the binocular vision testing except for phoria, accommodative and vergence facilities. The phoria and facility measurements were performed by a single examiner. The inter-examiner reliability was calculated for all the binocular vision parameters following the training phase, prior to the field work.

Detailed binocular vision and accommodation assessment

The binocular vision and accommodative assessment included the near point of convergence (NPC), phorias at distance and near using the modified Thorington method, fusional vergence amplitudes using prism bar, vergence facility using 12 base out/3 base in vergence flippers, near point of accommodation (NPA), accommodative response and monocular (right eye only) and binocular accommodative facility using ±2.00 D sphere accommodative flippers. The detailed procedures for these tests are described in a previous publication.[9]

Data management

Descriptive statistics were calculated for all of the binocular vision and accommodative tests in the different age groups. Intra-class correlation coefficient was used to determine the inter-examiner reliability for binocular vision parameters carried out by three different examiners. One-way analysis of variance (ANOVA) and linear regression were used to assess the developmental trend of the parameters among the various age groups. The normative data for the population were estimated from the sample using the mean and standard deviation of the measured parameters. The values of the accommodation and binocular vision parameters were rounded to the closest integer.

RESULTS

The mean age of the sample was 13.2 ± 2.3 and 11.6 ± 2.9 years in the rural and urban arms, respectively. Forty-eight per cent of the subjects were female in the rural sample and 42 per cent in the urban population. The intra-class coefficients (95 per cent confidence interval) for the binocular vision parameters were found to range between 0.72 to 0.9 and the reliability measures were within acceptable ranges as proposed in the literature.[7,12,13.] The normative values were estimated by combining the rural and urban population data (n = 637).

Results of the binocular vision and accommodative testing were compared across the age groups of seven to 17 using one-way ANOVA and post-hoc Bonferroni analyses. The developmental trend of binocular vision parameters with age was analysed through simple linear regression and these parameters are provided in Table 1. Post-hoc Bonferroni analysis with the conservative p-value (0.004) revealed significant differences for all accommodative tests (accommodative amplitudes, facility and lag) and for two binocular vision tests (near negative fusional

Age (number)	Mean AA ± SD	95% CI of mean	Hofstetter's average AA[30,31]
7 (41)	13.7 ± 1.3	13.3–14.1	16.4
8 (56)	13.2 ± 2	12.6–13.7	16.1
9 (51)	13.3 ± 2.6	12.6–14	15.8
10 (54)	13.2 ± 3.2	12.3–14	15.5
11 (52)	11.3 ± 2.6	10.5–11.9	15.2
12 (79)	11.8 ± 2.8	11.4–12.6	14.9
13 (92)	11.4 ± 3.2	10.7–12	14.6
14 (52)	10 ± 1.6	9.6–10.4	14.3
15 (66)	10.8 ± 2.1	10.3–11.3	14
16–17 (89)	10.6 ± 1.6	10.3–10.9	13.7
Grouped data			
7–10 (202)	13.3 ± 2.5	13–13.7	NA
11–17 (430)	11.1 ± 2.5	10.9–11.3	NA

Table 3. Mean amplitude of accommodation (AA) for ages

vergence recovery, vergence facility). We also looked for significant correlations with various age groups, in the post-hoc analysis in the statistically significant groups and these are reported in Table 1.

Due to differing visual demands between lower and higher grades at school and due to existing evidence in the literature that these groups may be different in regard to binocular vision and accommodative function,[14] the sample was analysed using two age groups (seven to 12 and 13 to 17 years old). There was no significant difference in the proportion of subjects with normal binocular vision in the two age groups (seven to 12 years: 337 out of 450 (74.8 per cent); 13 to 17 years: 300 out of 460 (65.2 per cent) Z-test; $p > 0.05$).

Statistically significant differences were found between the two age groups for accommodative testing (accommodative facility, lag) and binocular vision testing (NPC with accommodative target, vergence facility, near negative fusional vergence (break and recovery), distance positive fusional vergence and negative fusional vergence (break and recovery), near horizontal phoria. The data for accommodative amplitudes are provided in Table 3.

Linear regression analysis revealed a significant association between age and amplitude of accommodation (AA) with the linear regression equation:

AA = 16 − 0.3 × (age) (R^2 = 0.8; ANOVA $p < 0.0001$) (Figure 2).

We also identified two clusters of seven to 10 years and 11 to 17 years in the AA trend and hence, a grouped mean for these two clusters was calculated and represented (Table 3). As there were only 10 children in the 17 years age group, we grouped the 16 and 17 years age for analysis. Among the 637 children, five children did not report blur while testing AA and these data were excluded from the analyses.

Based on the results, the recommended values for accommodative and vergence parameters are provided in Table 2. For statistically insignificant differences between the age groups, the grouped mean is provided for the data and for significant difference in means between the age groups, separate data are provided (Table 1).

DISCUSSION

The results of this study provide normative data for binocular vision and accommodative testing for school children in the Indian population. NPC, horizontal phoria, vergence facility, AC/A ratio, accommodative amplitudes and accommodative facility were found to be different in our population compared to current standards.[6,7,15]

Statistically significant differences in cut-off values were found for a number of binocular vision and accommodative tests (Table 4). The values for NPC with penlight, vergence facility and accommodative amplitudes were remote compared to the existing reference[7] and better values for accommodative facility and phoria were found. The potential reasons for this difference are discussed below.

Comparison of binocular vision parameters obtained in our study with those of studies that have similar methodologies is presented in Table 4. Fusional vergence ranges were found to be clinically comparable to previously published normative data (Table 5).

The present study proposes the mean cut-off NPC break of 3 ± 3 cm and 7 ± 5 cm using an accommodation target and a penlight, respectively. The cut-off for NPC break with an accommodative target correlates with that of Scheiman and colleagues,[16] Chen, O'Leary and Howell[17] and for penlight with that of Jimenez and colleagues.[11] It has been reported that there is no difference between the break points obtained for NPC with accommodative target versus penlight among normal subjects[18] and penlight is a more sensitive test for diagnosing convergence insufficiency;[18,19] however, the results of our study show a significant difference in NPC values between accommodative target and penlight with red filter even among normal subjects.

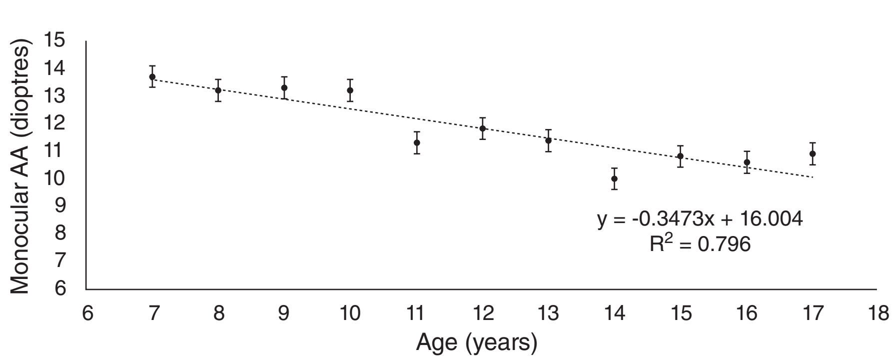

Figure 2. Age versus amplitude of accommodation (AA) among seven to 17-year-olds

	Study data mean ± SD	Morgan[6] and Scheiman and Wick[7] mean ± SD	p-value (one sample t-test)
Distance phoria	0.02 ± 1 esophoria	1 ± 2 exophoria	<0.001
Near phoria	−0.4 ± 2 exophoria	3 ± 3 exophoria	<0.001
Calculated AC/A ratio	5.4:1 ± 0.6	5.2:1 ± 2	<0.001
Step vergence testing			
Base-out (near)	Break: 26 ± 10	Break: 23 ± 8	<0.001
	Recovery: 21 ± 10	Recovery: 16 ± 6	<0.001
Base-in (near)	Break: 15 ± 4	Break: 12 ± 5	<0.001
	Recovery: 11 ± 4	Recovery: 7 ± 4	<0.001
Vergence facility testing	12 ± 4 cpm	15 ± 3 cpm	<0.001
(12 base-out/3 base-in)			
7–12 year old			
Near point of convergence			
Accommodative target	Break: 3 ± 3 cm	Break: 2.5 ± 2.5 cm	0.003
	Recovery: 4 ± 4 cm	Recovery: 4.5 ± 3 cm	<0.001
Penlight and red/green glasses	Break: 7 ± 5 cm	Break: 2.5 ± 4 cm	<0.001
	Recovery: 10 ± 7 cm	Recovery: 4.5 ± 5 cm	<0.001
Monocular accommodative facility			
6 years old	11 ± 4 cpm	5.5 ± 2.5 cpm	<0.001
7 years old		6.5 ± 2 cpm	
8–12 years old		7.0 ± 2.5 cpm	
13–30 years old	13 ± 5 cpm	11.0 ± 5 cpm	<0.001
Binocular accommodative facility			
6 years old	11 ± 4 cpm	3.0 ± 2.5 cpm	<0.001
7 years old		3.5 ± 2.5 cpm	
8–12 years old		5.0 ± 2.5 cpm	
Monocular estimate method retinoscopy	+0. 4 ± 0.2 D	+0.50 ± 0.25 D	<0.001

AC/A: accommodation convergence to accommodation ratio, cpm: cycles per minute

Table 4. Comparison of study data to published expected values

The phoria ranges in this Indian population sample indicate essentially orthophoria at distance in both the seven to 12 and 13 to 17 years age groups. At near, exophoria was found to increase in the older age group. The findings in our study are comparable to phoria data reported in the Spanish population[11] and indicate less exophoria compared to the expected finding proposed by Morgan.[6] This difference could be attributed to the difference in methodology and the tests used for phoria measurement.[20–23] The trend for the fusional vergence ranges in the present study is comparable with that of the existing normative data.[11,12,24,25]

The present study reveals a mean calculated AC/A ratio of 5.4:1 ± 0.6 and 5.7:1 ± 1.1 in the seven to 12 and 13 to 17 years, respectively. In 1972, Sen and Malik[26] determined the AC/A ratio for 100 normal subjects. The mean value was 2.28 (range: 0.5 to 4.0). The AC/A ratios of women were numerically slightly lower than males, although the difference was not statistically significant. Our data suggest a higher mean calculated AC/A ratio compared to the existing Indian data[26] and Morgan's data[6] but correlates with that of Jimenez and colleagues.[11] These differences are likely due to variation of measurement technique (calculated versus gradient). Our study used the calculated method compared to gradient method in Sen and Malik's study.[26] Data for vergence facility[27] and stereopsis[28] were comparable with the existing literature.

Our study is the first to report AA by age in Indian school children. Our equation (AA = 16 − 0.3 × [age]) predicts that the accommodative amplitudes are significantly lower in the Indian population by a minimum of 2.50 D compared to Hofstetter's proposed data[29–31] for average AA (18.5 − 0.3 × [age]). Rambo[32] measured the AA from 1,340 eyes in the age group 10 to 50 years. They found that there were rapid falls in the amplitude at 15 years and 37.5 years in Indians, when compared to the mid-European population. Among the seven to 17 years age range, we noticed a dip at 10 years of age, beyond which the AA was stable up to 17 years of age. Similar lower AAs compared to Hofstetter's data have been observed by Sterner, Gellerstedt and Sjöström[33] and a similar linear regression equation has been proposed by Chen, O'Leary and Howell.[17] In Sterner, Gellerstedt and Sjöström's study[33] of 76 children in the age range of six to 10 years, a mean difference of 3.50 D in the monocular measures of accommodation has been observed in more than 50 per cent of the sample. This difference in AA between ethnicities suggests the need for further investigation, to study the possible role of visual demand, geographical factors, such as latitude and its effect on amplitudes[34] and other physiological factors, such as lens curvature and zonular functions. We also observed better binocular compared to monocular amplitudes, which is consistent with previous literature.[17,33]

	Author	Morgan[6]	Scheiman and colleagues[7]	Jimenez and colleagues[1]	Antona and colleagues[12]	Present study
	Sample size	800	386	1,015	61	637
	Age (in years)	Pre-presbyopic adults	7–12	6–12	18–32	7–17
	Method	**Phorometry**	**Step vergence**	**MT/ step vergence**	**Step vergence**	**MT/ step vergence**
Phoria ± SD (in PD)	**Distance**	1 ± 2 exo	NA	0.6 ± 2 eso	NA	0.02 ± 1 eso
	Near	3 ± 5 exo	NA	0.4 ± 3 exo	NA	0.4 ± 2 exo
Vergence values (blur/ break/ recovery)	**Distance NFV**	x/7 ± 3/4 ± 2	NA	x/6 ± 2/4 ± 2	x/8.63 ± 1.94/6.26 ± 1.82	x/8 ± 2/6 ± 2
	Near NFV	13 ± 4/21 ± 4/13 ± 5	x/12 ± 5/7 ± 4	x/11 ± 3/7 ± 3	x/8.75 ± 3.37/12.14 ± 3.35	x/15 ± 4/11 ± 4
	Distance PFV	9 ± 4/19 ± 8/10 ± 4	NA	x/17 ± 7/11 ± 6	x/23.25 ± 7.68/14.5 ± 4.17	x/17 ± 8/12 ± 7
	Near PFV	17 ± 5/21 ± 6/11 ± 7	x/23 ± 8/16 ± 6	x/18 ± 13/8 ± 6	x/28.91 ± 9.09/19.65 ± 5.98	x/26 ± 10/21 ± 10

NA: not available, NFV: negative fusional vergence, PFV: positive fusional vergence

Table 5. Fusional vergence measures of the present study compared with the literature

The monocular and binocular accommodative facility mean were 11 ± 4 cycles/minute and 13 ± 5 in the age ranges of seven to 12 and 13 to 17, respectively. These values are higher compared to the literature,[7] and this may be attributed to the difference in testing. In this study, we used a simple grade level target for testing without a suppression check which yielded better values than the existing expected finding. As expected, the AA showed a significant developmental trend with age. Except for the accommodative amplitudes, various vergence and accommodation parameters also showed statistical significance, with significant R^2 values for parameters of accommodative facility, near negative fusional vergence break and recovery and vergence facility. As the clinical relevance for other parameters are limited by the low R^2 value, it is relevant to consider the grouped mean of the two age groups of seven to 12 and 13 to 17 as the normative reference for all the parameters.

A strength of this study is that it is a large, population-based sample. A limitation is that it was a convenience sample and we used cross-sectional data for comparing developmental trends of binocular vision parameters and future longitudinal studies are warranted. Also, cycloplegic refraction was not performed as part of the study in the community set-up because existing health-care protocols in India do not permit the instillation of eye drops at a school set-up. We used the monocular estimate method lag of accommodation as an indicator of potential latent hyperopia for any children with uncorrected refractive error. These children were referred to the base hospital for further management.

In summary, the present study suggests differences between the existing literature and Indian data for the expected findings for the age group of seven to 17 years, with clinically significant differences for NPC with penlight, phoria and vergence facility, AC/A ratio, NPA and accommodative facility. Beyond these differences, the data provided in this study serve as a valuable clinical reference for optometric practitioners in the Indian continent. This study provides the normative data for the Indian population between seven to 17 years of age.

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CLINICAL AND EXPERIMENTAL
OPTOMETRY

RESEARCH PAPER

Prevalence of non-strabismic anomalies of binocular vision in Tamil Nadu: report 2 of BAND study

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Background: Population-based studies on the prevalence of non-strabismic anomalies of binocular vision in ethnic Indians are more than two decades old. Based on indigenous normative data, the BAND (Binocular Vision Anomalies and Normative Data) study aims to report the prevalence of non-strabismic anomalies of binocular vision among school children in rural and urban Tamil Nadu.
Methods: This population-based, cross-sectional study was designed to estimate the prevalence of non-strabismic anomalies of binocular vision in the rural and urban population of Tamil Nadu. In four schools, two each in rural and urban arms, 920 children in the age range of seven to 17 years were included in the study. Comprehensive binocular vision assessment was done for all children including evaluation of vergence and accommodative systems. In the first phase of the study, normative data of parameters of binocular vision were assessed followed by prevalence estimates of non-strabismic anomalies of binocular vision.
Results: The mean and standard deviation of the age of the sample were 12.7 ± 2.7 years. The prevalence of non-strabismic anomalies of binocular vision in the urban and rural arms was found to be 31.5 and 29.6 per cent, respectively. Convergence insufficiency was the most prevalent (16.5 and 17.6 per cent in the urban and rural arms, respectively) among all the types of non-strabismic anomalies of binocular vision. There was no gender predilection and no statistically significant differences were observed between the rural and urban arms in the prevalence of non-strabismic anomalies of binocular vision (Z-test, $p > 0.05$). The prevalence of non-strabismic anomalies of binocular vision was found to be higher in the 13 to 17 years age group (36.2 per cent) compared to seven to 12 years (25.1 per cent) (Z-test, $p < 0.05$).
Conclusion: Non-strabismic binocular vision anomalies are highly prevalent among school children and the prevalence increases with age. With increasing near visual demands in the higher grades, these anomalies could significantly impact the reading efficiency of children. Thus, it is recommended that screening for anomalies of binocular vision should be integrated into the conventional vision screening protocol.

Key words: accommodation, accommodative infacility, binocular vision, convergence, convergence insufficiency, non-strabismic binocular vision anomalies, normative data, school screening

Accommodative and non-strabismic anomalies of binocular vision are reported to be highly prevalent among school children with estimates of close to 30 per cent according to a recent population-based study.[1] To the best of our knowledge, there are no data in the Indian literature on the prevalence of non-strabismic anomalies of binocular vision. Convergence insufficiency due to its high prevalence in clinical[2,3] and community settings[4,5] has been the non-strabismic anomaly of binocular vision most emphasized in the literature. Hospital-based studies in India, report prevalence rates of convergence insufficiency from 3.6 to 7.7 per cent;[6,7] however, these data are more than a decade old. Also, the prevalence ranges in various studies vary between 2.25 and 33 per cent and this is likely due to the inconsistency in the diagnostic cut-off and criteria.[1–8] Physiological and environmental factors, such as ethnicity, have been shown to influence the diagnostic cut-off of a parameter. This suggests that using an indigenous diagnostic cut-off for a population would best represent the prevalence of non-strabismic anomalies of binocular vision in that particular population.[5,9–11]

It has been reported that a high proportion of children with convergence insufficiency also have learning difficulties and the academic behaviour, assessed using an 'academic behaviour survey' showed significant improvement following vision therapy for convergence insufficiency.[12,13] With the increasing near visual demands, it is important to study the current prevalence of non-strabismic anomalies of binocular vision among school children, so that appropriate intervention could be planned. Hence, the BAND (Binocular Vision Anomalies and Normative Data) study group[14] designed this study to investigate the prevalence of non-strabismic anomalies of binocular vision among school children in rural and urban Tamil Nadu.

METHODS

This study is part of an epidemiological project named BAND and the detailed methods are available in a previous publication.[14] This research was approved by the Institutional Review Board of Vision Research Foundation and adheres to the tenets of the Declarations of Helsinki. The field work for the study began in February 2014 and was completed by December 2015. Two schools each in rural and urban locations were identified, based on non-probability convenience sampling. A pilot study was done to estimate the sample size followed by epidemiological field work, including comprehensive eye examination and binocular vision assessment. With an estimated sample of 936,[14] four public schools, two each in the rural and urban arms of Chennai were selected. A total of 3,024 children between seven and 17 years of age were screened in the four schools and 920 children were included, based on simple random sampling. Estimates of normative data were done in the first phase followed by estimates of prevalence of non-strabismic anomalies of binocular vision, based on the cut-off derived from the normative data.[11]

The first phase of the study focused on identifying refractive errors and ocular abnormalities other than non-strabismic anomalies of binocular vision. Vision screening was performed using an Elite School of Optometry pocket vision screener with a cut-off of 6/9.5 (0.2 logMAR) visual acuity,[15] versions, pupillary assessment, stereo-acuity at near using Randot stereo-plates and a penlight examination for gross ocular abnormalities. Static retinoscopy and subjective refraction was performed using a logMAR chart for children with refractive errors. If a subject was found to have a significant refractive error for the first time (myopia of −0.50 DS or more, hyperopia +0.50 DS or more, astigmatism 0.50 D or more) or if a change in refractive error of more than 0.50 D was detected in the spherical or cylindrical component during the refraction, glasses were prescribed and the binocular vision assessment was repeated two weeks after wearing the spectacle prescription. Tolerance limits for refractive errors were adopted from the Convergence Insufficiency Treatment Trial (CITT) protocol.[16] Children with strabismus, amblyopia and other ocular abnormalities were excluded from the prevalence study and were referred to the base hospital. Children were also excluded if they had any previous intraocular/strabismus surgery, ocular or head trauma or juvenile diabetes. To be eligible for the next phase of the study children had to be seven to 17 years of age and have visual acuity better than or equal to 6/9 and N6.

Detailed assessment of binocular vision and accommodation

After the vision screening, all children had a comprehensive binocular vision and accommodative assessment that included the near point of convergence, phorias at distance and near, fusional vergence amplitudes, vergence facility, near point of accommodation, accommodative response and monocular (right eye only) and binocular accommodative facility. The detailed procedures for these tests are described in a previous publication.[14]

The diagnosis of non-strabismic anomalies of binocular vision was based on the criteria suggested by Scheiman and Wick[17] for convergence insufficiency, convergence excess, divergence insufficiency, divergence excess, basic esophoria, basic exophoria, fusional vergence dysfunction, accommodative insufficiency, accommodative excess and accommodative infacility. As a first step, the normative data for binocular vision and accommodation parameters for the paediatric Indian population were estimated from this population (unpublished data) and these cut-off points were used to establish the diagnosis (Appendix I).[11] Children who were symptomatic and met the inclusion criteria for any of the diagnoses for non-strabismic anomalies of binocular vision were included in the prevalence study.

Data measurement

Data analysis was performed using Microsoft Excel 2007 and SPSS-V.18.0. Descriptive statistics were calculated for all the anomalies of binocular vision and differences in proportions were analysed between the rural and urban populations. Similarly, differences in prevalence between the gender and age groups were analysed. Statistical comparisons were made using Z-test for proportions with the p-value cut-off of 0.05 for statistical significance.

RESULTS

A total of 3,024 children aged between seven and 17 years were screened in four schools and 920 children were included in the study. The mean age and standard deviation of the sample were 13.2 ± 2.3 and 11.6 ± 2.9 years in the rural and urban arms, respectively. The prevalence of refractive errors and ocular diseases are provided in Table 1.

The demographic details and the distribution of non-strabismic anomalies of binocular vision are represented in Table 2. There was no significant difference in the prevalence between rural and urban populations for the overall prevalence of non-strabismic anomalies of binocular vision or for the subtypes ($p > 0.05$, Z-test).

Convergence insufficiency was the most prevalent non-strabismic anomaly of binocular vision in both the rural and urban populations followed by accommodative infacility (Table 2). The proportion of non-strabismic anomalies of binocular vision was not statistically significant between the rural and urban populations. Hence for age-based analyses, the rural and urban data were analysed together. Two age groups of seven to 12 years and 13 to 17 years were identified, based on the previous analyses from normative data from the same population.[11]

Also, other than convergence insufficiency and accommodative infacility, other subtypes of non-strabismic anomalies of binocular vision showed prevalence close to one per cent and hence statistical analysis was restricted to convergence insufficiency and accommodative infacility due to adequate sampling. Age-based analyses of the prevalence of non-strabismic anomalies of binocular vision revealed a significant increase in prevalence in the 13 to 17 years age group and these results were statistically significant (Z-test, $p < 0.0001$). Similarly, statistically significant differences were observed for the subtypes of convergence insufficiency and accommodative infacility (Z-test, $p < 0.0001$) (Table 3).

As convergence insufficiency was the most prevalent non-strabismic anomaly of

	Rural N = 1,435	Urban N = 1,589
Refractive errors		
Myopia	28 (1.95%)	34 (2.1%)
Hyperopia	4 (0.3%)	8 (0.5%)
Astigmatism	18 (1.25%)	37 (2.3%)
Strabismus and amblyopia	7	2
Ocular diseases (list below)	16 (1.1%)	21 (1.3%)
Cataract	2	5
Nystagmus	1	5
Retinal pathology	4	5
Congenital colour blindness	4	0
Ptosis	1	4
Corneal disorders	1	2
Iris coloboma	1	0
Third nerve palsy	2	0

Table 1. Prevalence of refractive errors and ocular diseases

	Rural N = 358	Urban N = 562
Mean (SD) age	13.2 ± 2.3	11.6 ± 2.9
Male: female	185:173	324:238
Normal binocular vision	252 (70.4%)	385 (68.5%)
Overall non-strabismic anomalies of binocular vision	106 (29.6%)	177 (31.5%)
Convergence insufficiency	63 (17.6%)	93 (16.5%)
Convergence excess	6 (0.8%)	10 (1.4%)
Divergence excess	0	2 (0.4%)
Fusional vergence dysfunction	3 (0.8%)	5 (1.3%)
Divergence insufficiency	1	0
Basic esophoria	1 (0.3%)	0
Basic exophoria	0	0
Vergence infacility	0	2
Accommodative infacility	29 (7%)	64 (10.7%)
Accommodative excess	3 (0.8%)	0
Accommodative insufficiency	0	1 (0.2%)

Table 2. Prevalence of non-strabismic anomalies of binocular vision in the rural and urban populations

binocular vision among all the subtypes, followed by accommodative infacility, the mean values of the parameters of binocular vision in subjects with convergence insufficiency and accommodative infacility are listed in Table 4. These parameters were compared with the data of the normal binocular vision group, from the same population.[11] All the binocular vision parameters were significantly different between the convergence insufficiency and normal binocular vision group except for the monocular estimate method retinoscopic value, near vertical muscle imbalance measure, near and distance negative fusional vergences (unpaired t-test; $p < 0.0001$). As a high prevalence of accommodative insufficiency is reported as a co-morbid condition in convergence insufficiency,[10,18,19] we analysed the amplitude of accommodation in convergence insufficiency with the normal binocular vision group and the difference in amplitude of accommodation was found to be statistically significant (unpaired t-test, $p < 0.001$) but these results were clinically insignificant (mean amplitude of accommodation in convergence insufficiency: 10.5 ± 2.9; normal binocular vision: 11.8 ± 3.1; mean difference (95 per cent confidence interval [CI]): 1.3 D [0.7 to 1.9]). In the accommodative infacility group, monocular and binocular accommodative facility and near point of convergence with penlight/red filter (NPC-PLR) break and recovery values were significantly different from the normal binocular vision group (unpaired t-test; NPC-PLR, $p < 0.05$; accommodative facility – monocular and binocular, $p < 0.0001$).

As detailed in the methods, subjects who failed the screening criteria were referred for further management and subjects who passed the screening criteria were included in the study. Subjects who passed the comprehensive binocular vision assessment were included in the normative project. Subjects with visual symptoms and identified as having an anomaly of binocular vision based on the binocular vision assessment were included for the prevalence project. Yet, during this process, there were subjects who had an asymptomatic anomaly of binocular vision and others that were symptomatic but had normal binocular vision. These combinations were analysed and data from these subjects were reassessed prior to classifying them to one of the two groups of normal binocular vision versus non-strabismic anomalies of binocular vision. Seventy-three children (7.9 per cent) fell into one of these two groups. Fifty-eight (6.3 per cent) were asymptomatic but still failed the tests of binocular vision and were classified as having non-strabismic anomalies of binocular vision. Fifteen (1.6 per cent) were symptomatic but had normal parameters of binocular vision and were classified as normal binocular vision (Table 5).

DISCUSSION

Our study is the first to report the prevalence of non-strabismic binocular vision

	7–12 years n (%)	13–17 years n (%)
TOTAL SAMPLE	450	470
Normal binocular vision	337 (74.8)	300 (65.2)
Overall non-strabismic anomalies of binocular vision	113 (25.1)	170 (36.2)
Convergence insufficiency	66 (14.6)	90 (19.6)
Accommodative infacility	42 (9.3)	51 (11.1)

Table 3. Prevalence of non-strabismic anomalies of binocular vision in the seven to 12 years and 13 to 17 years age groups in the overall population

anomalies in the rural and urban populations in southern India. The prevalence of non-strabismic anomalies of binocular vision was estimated to be 31.5 and 29.6 per cent in the rural and urban populations, respectively. Among primary school children, recent population-based data in ethnic Asians reported a prevalence of 28.5 per cent of non-strabismic anomalies of binocular vision.[1] Similarly, in a clinical paediatric population, a previous study showed that non-strabismic anomalies of binocular vision are almost 8.5 to 9.7 times more common than the prevalence of

BV parameters		CI N = 156	AIF N = 93	Normative reference N = 637
Mean age, years		12.7 ± 2.7	12.6 ± 2.6	12 ± 2.8
NPC-AT, cm	BREAK	7.4 ± 5.2	3.5 ± 3.8	3 ± 3
	REC	9.5 ± 7.3	4.3 ± 4.7	4 ± 4
NPC-PLR, cm	BREAK	18.4 ± 10.8	9 ± 8	7 ± 5
	REC	23.5 ± 11.8	12.1 ± 10.3	10 ± 7
Amplitude of accommodation, D	M/O	10.5 ± 2.8	11.4 ± 3	7–10 years: 13 ± 3 11–17 years: 11 ± 2
	B/O	11 ± 3.3	12 ± 3	7–10 years: 13 ± 3 11–17 years: 11 ± 3
Near PFV, PD	BREAK	16.6 ± 7.6	23.6 ± 10.4	26 ± 10
	REC	12.8 ± 6.3	17.7 ± 8	21 ± 10
Near NFV, PD	BREAK	13.9 ± 4	14 ± 4.8	15 ± 4
	REC	11 ± 3.9	10.5 ± 4.2	11 ± 4
Distance PFV, PD	BREAK	12.1 ± 6	15.2 ± 5.8	17 ± 8
	REC	8.4 ± 5.2	11 ± 4.8	12 ± 7
Distance NFV, PD	BREAK	7.6 ± 2.8	8.3 ± 2.3	8 ± 2
	REC	5 ± 2.1	5.8 ± 2	6 ± 2
Accommodative facility, CPM	M/O	9.5 ± 5.6	4 ± 2	7–12 years: 11 ± 4 13–17 years: 14 ± 5
	B/O	9.8 ± 5.4	5.3 ± 2.7	7–12 years: 10 ± 4 13–17 years: 14 ± 5
Vergence facility, CPM		8.2 ± 5.4	11 ± 4.5	7–12 years: 12 ± 4 13–17 years: 14 ± 4
MIM-Horizontal, PD	DIST	–0.9 ± 2.1	0 ± 0.8	0.02 ± 1
	NEAR	–4.5 ± 3.9	–0.1 ± 1.8	–0.4 ± 2
MIM-Vertical, PD	DIST	0 ± 0.3	0.02 ± 0.4	0 ± 0.5
	NEAR	0.1 ± 0.7	0.02 ± 0.4	0 ± 0.5
MEM, D		0.3 ± 0.2	0.3 ± 0.2	0.4 ± 0.2
AC/A		4.5 ± 1	5.8 ± 0.6	5.4 ± 0.6

AC/A: accommodative convergence/accommodation ratio, CPM: cycles per minute, D: dioptres, MEM: monocular estimate method, MIM: muscle imbalance measure, NFV: negative fusional vergence, NPC-AT: near point of convergence with accommodative target, NPC-PLR: near point of convergence with penlight and red filter, PD: prism dioptres, PFV: positive fusional vergence

Table 4. Mean values of binocular vision parameters in convergence insufficiency (CI) and accommodative infacility (AIF) subjects

	NSABV	Normal BV	Total
Symptomatic	225	15	240
Asymptomatic	58	622	680
Total	283	637	920

Table 5. Number of children with symptomatic versus asymptomatic non-strabismic anomalies of binocular vision

ocular disease in children between six and 18 years of age,[3] with convergence insufficiency being the most prevalent of all types of non-strabismic anomalies of binocular vision.[1,4,5]

Convergence insufficiency was the most prevalent non-strabismic anomaly of binocular vision (16.5 and 17.6 per cent in the urban and rural arms, respectively) in the BAND study. Similar to our study results, convergence insufficiency has been reported to be the most common non-strabismic anomaly of binocular vision in previous reports[1,4–7] but there is a wide range of prevalences between 2.25 to 33 per cent[1–8,20] in other studies and this difference could possibly be attributed to the diagnostic criteria used. The prevalence of other types of non-strabismic anomalies of binocular vision in Indians is not known to the best of our knowledge.

Recent studies[1,4] in other ethnic groups that use a combination of parameters, rather than a single parameter (for example, near point of convergence) report prevalence similar to our study. We adopted the standard criteria suggested by Scheiman and colleagues[15] to diagnose non-strabismic anomalies of binocular vision and instead of using Morgan's expected values,[20] we used expected values derived from the normative data from our community.[11]

We found a potential age effect with the prevalence of non-strabismic anomalies of binocular vision increasing from 25.1 per cent in the seven to 12 years age group to 36.2 per cent in the 13 to 17 years age group. This trend may be related to the increased near visual demands in older children. In an adult population above 19 years of age, one in six adults was diagnosed with convergence insufficiency[21] and a significant increase in exophoria of seven prism dioptres (PD) was seen by 20 years in one-fourth of the sample after the initial diagnosis. Also, a significant association between reading and non-strabismic anomalies of binocular vision has been reported in the literature.[22,23] Thus, it becomes important to understand the impact of non-strabismic anomalies of binocular vision on reading and academic performance and these data are analysed separately as part of the BAND project.

Convergence insufficiency (14.6 and 19.6 per cent in the seven to 12 and 13 to 17 years age groups), followed by accommodative infacility (9.3 and 11.1 per cent in the seven to 12 and 13 to 17 years age groups) was the most prevalent non-strabismic anomalies of binocular vision. The prevalence of the remaining subtypes was less than two per cent. Using the diagnostic criteria and cut-off points proposed by Scheiman and colleagues,[17] the prevalence estimates for convergence insufficiency and accommodative infacility are reduced to six per cent each in the current sample. This suggests that an indigenous cut-off is more appropriate to detect symptomatic non-strabismic anomalies of binocular vision in the Indian population. Another potential difference for this prevalence variability is the cut-off for phoria that we used in our study. We observed in our sample, that a receded near point of convergence and/or a reduced near positive fusional vergence was present even when the distance and near phoria difference did not exceed 4 PD as per the standard CITT protocol.[16] The upper limit of the 95 per cent CI for the mean difference between the distance and near phoria was two PD in the normative data and so we applied this criterion to the classification of convergence insufficiency, although these values are liberal and overlap with test-retest variability range. This is one reason to recommend that a group of criteria be applied to reach a diagnosis rather than using a single parameter.

It is interesting to note that the prevalence of accommodative insufficiency is 0.2 per cent in our population, in contrast to the higher prevalence reported in the existing literature.[1,4,10,18] One of the main reasons for this finding may be the indigenous cut-off for amplitude of accommodation used in our population. If the cut-off had been based on conventional Hofstetter's minimum expected amplitude of accommodation,[24,25] 77 (eight per cent) out of the overall 920 would have been diagnosed with accommodative insufficiency. We also did not find children who reported symptoms of near visual blur, a finding consistent with diagnosis of accommodative insufficiency. Similar findings of differences in amplitude of accommodation from Hofstetter's data have been reported earlier in the adult population in India[26] and also by Sterner, Gellerstedt and Sjöström.[10] It is also important to note that the mean amplitudes of accommodation in convergence insufficiency were statistically significantly different from the normal binocular vision group, although these differences were clinically insignificant.

In this study, a large proportion of children (20.5 per cent) were asymptomatic in the presence of abnormal parameters of binocular vision. The literature suggests that symptomatic individuals are more likely to fail Sheard's criterion.[27,28] In our population, in the asymptomatic non-strabismic anomalies of binocular vision group, 12.1 per cent failed Sheard's criterion, whereas in the symptomatic group, 13.8 per cent failed Sheard's criterion. These proportions were not statistically significant (Z-test; $p > 0.05$), thus revealing no significant association between Sheard's criterion and symptoms. Increased variability and reduced reliability associated with vergence testing could be reasons for this finding.[17]

We also re-applied the standard clinical criteria for diagnosis proposed by Scheiman and Wick[17] to the asymptomatic non-strabismic anomalies of binocular vision group. When these criteria were applied, the proportion of asymptomatic non-strabismic anomalies of binocular vision reduced to 14.8 from 20.5 per cent. Out of the 58 children, 37 had convergence insufficiency, 15 had accommodative infacility, two had convergence excess and four had fusional vergence dysfunction. This suggests that the criteria for diagnosis do not significantly change the proportion of asymptomatic non-strabismic anomalies of binocular vision. We have not done any intervention for the asymptomatic non-strabismic anomalies of binocular vision in this study, although we educated the children about the potential visual symptoms that could develop over a period of time. Also, there is no clarity on why these children are asymptomatic, although reduced visual demands, cognition and awareness could be hypothesised as possible reasons. Studies have shown an association between symptomatic convergence insufficiency and academic performance[12] and vision therapy for convergence insufficiency significantly improved academic performance.[13] These results could be extrapolated to the overall non-strabismic anomalies of binocular vision and thus, demand the need for screening for non-strabismic anomalies of binocular vision among children, so that appropriate intervention can be planned.

The higher prevalence of non-strabismic anomalies of binocular vision reported in our study has implications for the public health strategies adopted with respect to eye care among Indian school children. Vision screening protocol designed only to screen for refractive errors and ocular pathology will miss a significant number of important non-strabismic anomalies of binocular vision.

CONCLUSION

Non-strabismic anomalies of binocular vision are highly prevalent among school children in both rural and urban areas. Convergence insufficiency is the most common non-strabismic anomaly of binocular vision followed by accommodative infacility. Screening for anomalies of binocular vision should be part of the vision screening protocol and appropriate intervention should be planned for non-strabismic anomalies of binocular vision.

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APPENDIX I: DIAGNOSTIC CRITERIA FOR NON-STRABISMIC ANOMALIES OF BINOCULAR VISION

The generic criteria for the diagnosis are adapted from Scheiman and Wick[15] and the specific cut-off has been derived from the normative data from phase one of the current study.[11]

1. Convergence insufficiency

Symptoms:

Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, intermittent diplopia.

Signs:

1. Greater exophoria for near than distance by more than 2 prism dioptres (PD).
2. Receded near point of convergence (NPC) break with accommodative target greater than 6 cm.
3. Receded NPC break with penlight and red filter greater than 12 cm.
4. Reduced positive fusional vergence (PFV) break less than 15 PD.
5. Difficulty clearing +2.00 DS with binocular accommodative facility (BAF) less then 8 cycles per minute (CPM).

For diagnosis: Two out of the first four criteria are mandatory.

2. Divergence insufficiency

Symptoms:

Associated with distance viewing. The most common include intermittent diplopia for distance, headache and eyestrain.

Signs:

1. Esophoria greater for distance than near by more than 3 PD.
2. Reduced negative fusional vergence (NFV) break less than 6 PD for distance.
3. Difficulty clearing −2.00 DS with binocular accommodative facility less than 8 CPM.

For diagnosis: Criterion 1 is mandatory with a minimum of one criterion from 2 and 3.

3. Convergence excess

Symptoms:

Associated with reading or other near tasks and generally worse at end of day.

The most common include asthenopia, headaches and intermittent diplopia.
Signs:
1. Esophoria greater at near than distance by 3 PD.
2. Reduced NFV break less than 10 PD at near.
3. Difficulty with binocular accommodative facility with −2.00 DS less than 8 CPM.
4. High monocular estimate method (MEM) lag of accommodation greater than +1.25 DS.

For diagnosis: Criterion 1 is mandatory with a minimum of one criterion from 2, 3 or 4.

4. Divergence excess

Symptoms:

Associated with distance viewing than near. The most common include intermittent diplopia for distance, headache and eyestrain.
Signs:
1. Intermittent to constant exo deviation for distance greater than near of more than 4 PD.
2. Low positive fusional vergence break less than 10 PD for distance.
3. Difficulty clearing +2.00 DS with BAF less than 8 CPM.

For diagnosis: Criterion 1 is mandatory with a minimum of one criterion from 2 and 3.

5. Fusional vergence dysfunction

Symptoms:

Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, blurred vision and difficulty concentrating on near visual tasks.
Signs:
1. Reduced NFV less than 10 PD and PFV less than 15 PD break at near and reduced NFV less than 6 PD and PFV less than 10 PD break at distance.
2. Difficulty with both ± 2.00 DS in BAF – less than 8 CPM.
3. Normal monocular accommodative facility (MAF) more than 8 CPM.

For diagnosis: One out of the first two criteria is mandatory; criterion 3 is mandatory.

6. Basic esophoria

Symptoms:

Associated with reading or other near tasks and with distant activities. The most common near point complaints include eyestrain, headaches and blurred vision. Common symptoms associated with distance include blurred vision and diplopia, when watching television and in classroom.
Signs:
1. Equal magnitude of esophoria at distance and near.
2. Reduced NFV break less than 6 PD at distance and less than 10 PD at near.
3. Difficulty with BAF with −2.00 DS less than 8 CPM.

For diagnosis: Criteria 1 is mandatory with one out of the next two criteria.

7. Basic exophoria

Symptoms:

Associated with reading or other near tasks and with near and distant activities. The most common near point complaints include eyestrain, headaches and blurred vision.
Signs:
1. Equal amount of exophoria at distance and near.
2. Receded NPC break less than 6 cm with accommodative target.
3. Reduced PFV break less than 10 PD for distance and less than 15 PD at near.
4. Difficulty clearing +2.00 DS with BAF less than 8 CPM.

For diagnosis: Criterion 1 is mandatory with two out of the next three criteria.

8. Accommodative insufficiency

Symptoms:

Blurred near vision, discomfort and strain associated with near tasks, fatigue associated with near point tasks, difficulty with attention and concentration when reading.
Signs:
1. Blur at near point testing at Harmon's distance.
2. Reduced amplitude of accommodation by 2.00 D or more from the average amplitude of accommodation derived from the normative equation 16 – 0.3 (age).
3. Difficulty with MAF – less than 7 CPM and BAF less than 8 CPM with −2.00 DS.
4. High monocular estimate method lag of accommodation (more than +1.25 DS).

For diagnosis: Criteria 1 and 2 are mandatory with one out of the next two criteria.

9. Accommodative excess

Symptoms:

Blurred distance vision worse after reading or other close work and often worse toward the end of the day, headaches and eyestrain after short periods of reading, difficulty focusing from far to near, sensitivity to light.
Signs:
1. Low monocular estimate method (less than or equal to plano) (lead of accommodation).
2. Esophoria for near more than 3 PD.
3. Variable visual acuity findings.
4. Variable static retinoscopic and subjective refraction.

For diagnosis: Criteria 1 and 2 are mandatory with one out of the next two criteria.

10. Accommodative infacility

Symptoms:

Blurred near vision, blurred distance vision after near visual tasks and vice versa, delayed focusing of objects, discomfort and strain associated with near tasks, fatigue associated with near tasks, difficulty with attention and concentration when reading.
Signs:
1. Difficulty with MAF less than 7 CPM and/or BAF less than 8 CPM with both ±2.00 DS in the presence of NFV findings.
2. Normal amplitude of accommodation.
3. Normal fusional vergence amplitudes.

For diagnosis: All three criteria are mandatory.