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Epidemiology of binocular vision anomalies in children: a narrative review

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Abstract

The ability to see simultaneously with both eyes working together is known as binocular single vision. A healthy anatomical, motor, and sensory system is necessary for single binocular vision. Thus, binocular vision anomalies are caused by abnormalities in the operation of all three systems that interfere with single binocular vision. This study's objective is to examine the frequency, types and risk factors of binocular vision abnormalities in school age children. The study adopted a narrative review methodology. Using search engines like PubMed and Google Scholar, as well as the Mendeley reference library for citation, published material from Nigeria, sub-Saharan Africa, and throughout the world was found and evaluated. The results indicate that between 34.3% and 76.5% of people have binocular vision abnormalities. Both strabismic (SBVA) and non-strabismic binocular vision abnormalities (NSBVA) were types of BVAs, with respective prevalence of 12.85% for SBVA and 76.5% for NSBVA. While accommodative insufficiency was the most prevalent accommodative binocular vision defect, convergence insufficiency was the most occurring vergence dysfunction. Headache, diplopia, and blurred vision were the visual symptoms that people reported the most, and were more common in dyslexic children than non-dyslexic children. In conclusion, binocular vision anomalies are vision defects that affects school age children globally with varying prevalence in different settings. This review therefore, emphasizes the necessity of conducting a comprehensive evaluation of binocular vision status of children as prerequisite for admittance of students into schools.

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1. Introduction

An individual's ability to focus on a single object with both eyes is affected by binocular vision anomalies [1]. Among these are conditions that hinder the brain's ability to combine the images into a single image from the two eyes [2]. Binocular vision anomaly (BVA) is an all-encompassing term that may be used to describe a wide range of problems than a particular one, and there are several potential causes of each of those disorders [3]. Good binocular vision requires proper anatomical, motor, and sensory systems. The fusion and coordination of information from each of the two eyes into a single binocular percept is referred to as

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single binocular vision. Therefore, binocular vision anomalies are caused by abnormalities in the operation of all three systems (i.e., anatomical, motor, and sensory) that interfere with single binocular vision. Strabismus, amblyopia, divergence insufficiency, divergence excess, convergence insufficiency, convergence excess, accommodation anomalies, and nystagmus are a few examples of these vision anomalies [4, 5].

Studies have shown that children suffer from binocular vision abnormalities with varying prevalence across populations and settings. A review by Pillay (2021) reports that convergence insufficiency (CI) prevalence ranges from 5.46% to 13.00% in non-clinical populations and 3.50% to 18.00% in clinical settings [6]. Among primary school children, the prevalence ranges from 6.80% to 31.40%, and in high school populations, it may reach 32.60%, depending on diagnostic criteria [6]. In South Korea, a study found that 28.55% of primary school children exhibited non-strabismic binocular dysfunction, with 13.2% having accommodative issues and 9% having vergence problems, convergence insufficiency being the most common [7]. The prevalence of binocular vision anomalies in Nigerian children varies by region and study. In Northern Nigeria, the 2024 study by Mukhtar *et al.* found a high prevalence of BVAs in both dyslexic and non-dyslexic children, with accommodative insufficiency significantly more common in dyslexic children (45.5% vs. 18.2%) [3]. In Abia State, 16.8% of schoolchildren had accommodative anomalies, including 3.9% accommodative insufficiency, 2.8% accommodative excess, and 10.1% accommodative infacility [8].

Binocular vision anomalies, particularly convergence insufficiency, affect reading, writing, and attention spans, which are linked to poor academic performance, decline in educational attainment, and difficulty completing tasks. A large number of binocular vision disorders are non-strabismic, which means that even when the eyes are aligned, binocular vision issues still arise. Blurred vision, headaches, eye strain, and trouble with close-range activities like writing and reading might result from these abnormalities [9, 10]. This review is aimed at revealing the burden of binocular vision anomalies in school-age children in terms of their frequency, types, and risk factors with emphasis in Nigeria.

2. Materials and methods

This study employed a narrative review design to synthesize existing evidence on the relevance of binocular vision anomalies. A total of sixty (60) published literature were first found by searching electronic resources such as PubMed, Google Scholar, and African Journals Online as well as Mendeley Reference Library for citation. Manual searches of pertinent studies' reference lists yielded more articles. Binocular vision abnormalities, strabismic BVA, non-strabismic BVA, refractive errors, and strabismic BVA in school-age children were among the search phrases. Boolean operators such as "AND" and "OR" were applied to refine search outcomes.

Peer-reviewed journal publications, books, and national or international health frameworks published in English that specifically addressed binocular vision anomalies were among the inclusion criteria. Although older landmark articles were included because of their conceptual and historical value, research published within the last five years were given preference to ensure relevancy. Researches from low- and middle-income nations, including Nigeria and sub-Saharan Africa, were given priority.

Exclusion criteria included duplicate publications, opinion pieces without empirical or policy relevance, studies lacking methodological clarity, and articles focused solely on binocular vision without linkage to binocular vision anomalies. Following title and abstract screening, 40 articles were shortlisted, and full-text review resulted in 33 studies being included in the final review.

3. Results

3.1. Global prevalence of binocular vision anomalies

3.1.1. Strabismic binocular vision anomalies

According to a study conducted by Donahue (2006) among preschool-aged children with anisometropia in the United States, the onset of amblyopia increased from 14% in children aged one year or younger to 76% in 5-year-olds (Figure 1). The severity of amblyopia was classified based on interocular visual acuity difference as follows: Mild amblyopia: 1 to 2 logMAR lines difference, Moderate amblyopia: 3 to 4 logMAR lines difference, and Severe amblyopia: 5 or more logMAR lines difference. This classification was applied to assess the depth of amblyopia in preschool-aged children with anisometropia. The prevalence of moderate amblyopia increased gradually to 45% (children aged 6 to 7 years) from 2% (ages 0 to 1 year) and 17% (age 2). The degree of amblyopia in children with strabismus was comparatively consistent (30% for ages 0–2 years; 42% for ages 3–4 years; and 44% for ages 5–7 years).

For children aged 0 to 3 years, severe amblyopia was uncommon; at age 4, it was 9%, and at age 5, it was 14%. The depth and frequency of amblyopia (the amblyopic eye's best-corrected visual acuity) was 30% in children aged 0–2 years, 42% in children aged 3–4 years, and 44% in children aged 5–7 years.

Numerous studies have been carried out globally in recent years to ascertain the frequency of anomalies in children's binocular vision and adolescents [11]. Various literature opined that the occurrence of BVA varies between 41.5% and 76.5% as shown in Figure 2. In Mangalore, India, the percentage of college students with impaired binocular vision is 76.5% [12]. Similar results from a study carried out in Nepal showed that 74% of people have binocular vision abnormalities [13]. Binocular vision abnormalities

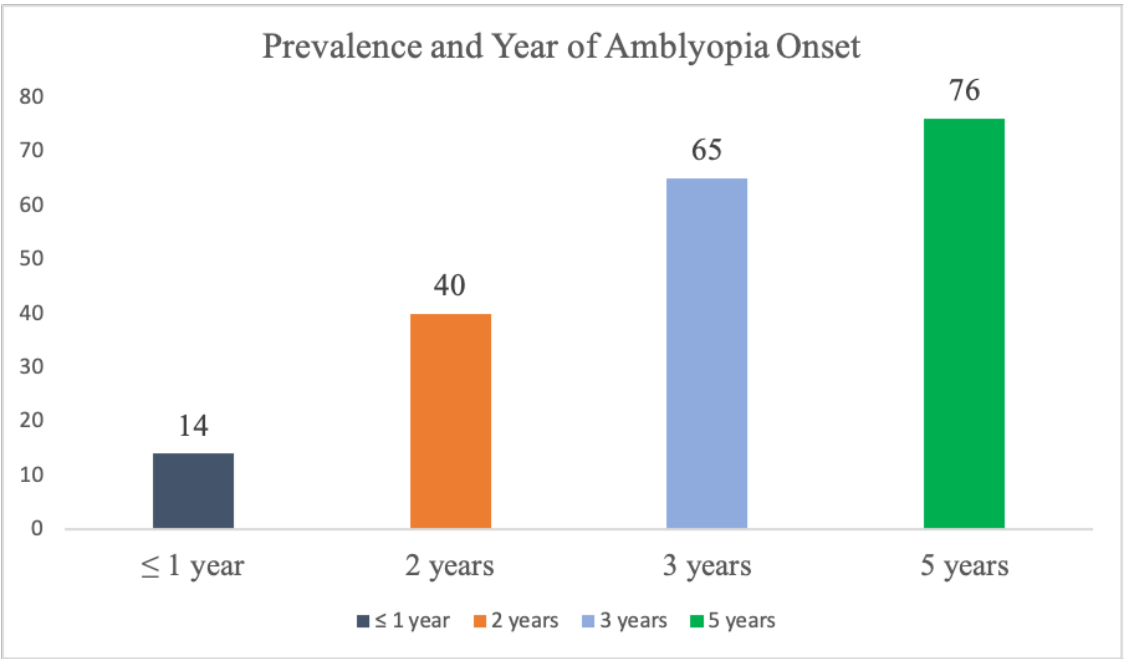

Figure 1: Prevalence and year of amblyopia onset in pre-school age children.

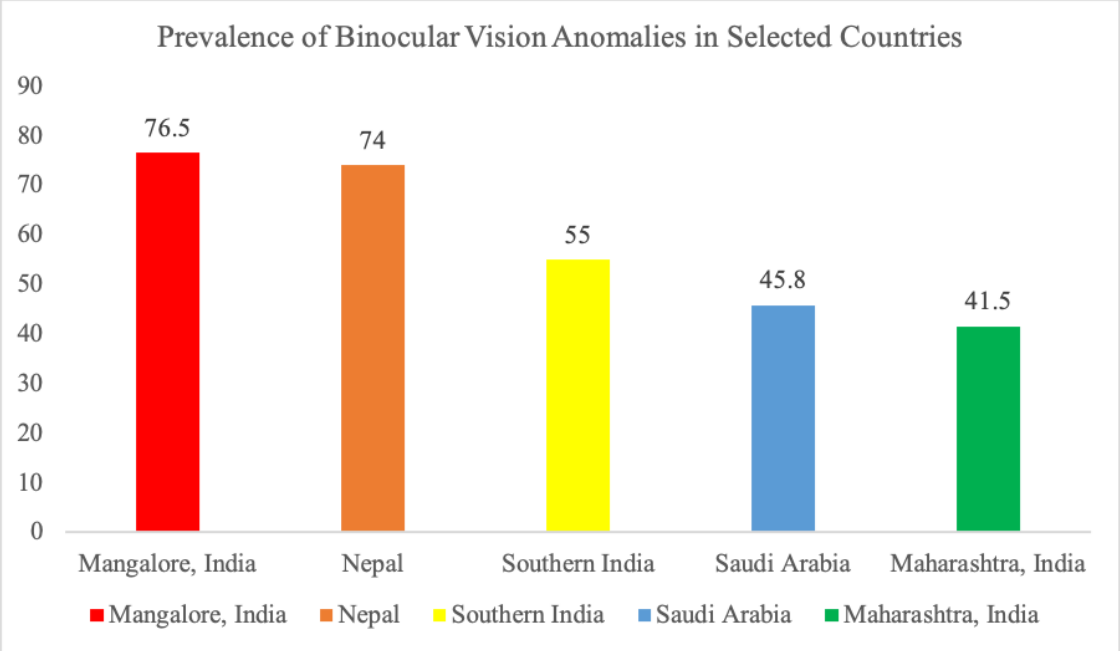

Figure 2: Binocular vision anomalies frequency in some countries.

were detected in 55% of the sample population in another investigation carried out in southern India [14]. On the other end of the spectrum, however, studies carried out in Saudi Arabia and Maharashtra, India, as Alghamdi *et al.* stated [15] as well as Tiwari *et al.* [16], revealed a prevalence of 45.8% and 41.5%, respectively.

3.2. Non-strabismic binocular vision anomalies

Studies conducted in North India, Portugal, and South Africa, as shown in Figure 3, revealed that the most occurring non-strabismic BVA were convergence insufficiency, accommodative infacility, and accommodative insufficiency [17, 18].

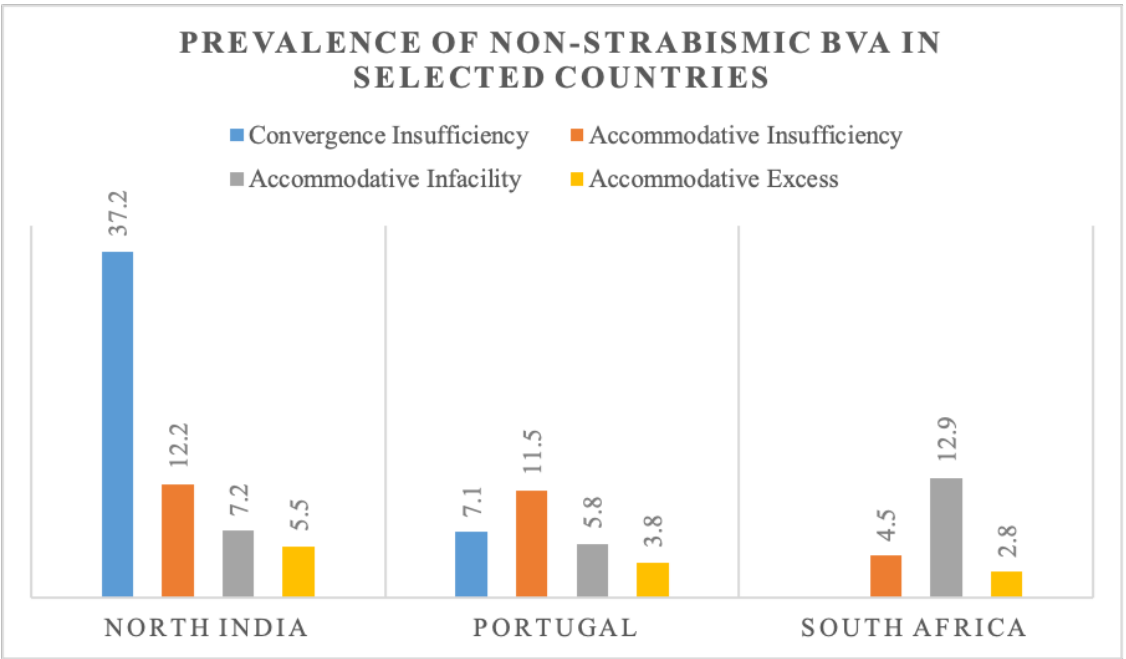

Figure 3: Prevalence of non-strabismic BVA.

3.3. Relationship between refractive errors and binocular vision anomalies

Numerous research have examined the frequency of refractive error and its demographic distribution, demonstrating that binocular vision defect is a prevalent abnormality that impacts a significant fraction of the world's population. Research by Alghamdi *et al.* [15] in Saudi Arabia and another by Besufikad *et al.* [19] in Ethiopia discovered that in 44.9% and 52.4% of the instances, respectively, myopia was the cause.

In southern India according to another research undertaken [14], 24% of the sample population had myopia. It was discovered that 8.2% of all refractive errors in Saudi Arabia were hyperopia [15]. Similar results were found by Besufikad *et al.*, who reported a 28.5% prevalence [19]. In Saudi Arabia, the prevalence of astigmatism was 7.3% [15] and 11% [14] respectively.

In Maharashtra, India, Tiwari *et al.* conducted another study that identified a significant prevalence of refractive error in both the normal and binocular vision anomaly groups, although the results were equivocal about the association between the two conditions [16]. Furthermore, research by Darko-Takyi *et al.* claims that 34.3% of people in Ghana have binocular vision abnormalities. They also found that 24% of refractive error was astigmatism [20]. The precise proportion of those with refractive error who also have binocular vision abnormalities was not disclosed in most of these investigations [15, 19]. In contrast, while Besufikad *et al.* showed that the prevalence of refractive error was 18.3% [19], Alghamdi *et al.* [15] study found that 64.6% of participants had both binocular vision abnormalities and refractive error. It is noteworthy that the findings exhibit no statistically significant relationship between refractive errors and impairments of binocular vision, indicating that there may not be a substantial correlation between the two conditions. However, Akhgary *et al.* [21] studied the frequency of amblyopia, anisometropia, and strabismic binocular abnormalities (SBVA) among Iranian patients seen in the optometry clinic of the rehabilitation faculty at Shahid Beheshti Medical University, and found that 10.67% of patients had anisometropia, 1.5% had anisometropic amblyopia, 0.17% had esotropia and 0.17% had amblyopia sequel to amblyopia with exotropia and 0.33% had convergence insufficiency.

3.4. National prevalence of binocular vision anomalies

Study carried out by Atowa *et al.* to ascertain the frequency of accommodating abnormalities among Nigerian school children in Abia State, revealed that among the 16.8% of kids with accommodative abnormalities, accommodative excess was 2.8%, accommodative insufficiency was 3.9%, and accommodative infacility was 10.1% [8]. Mukhtar *et al.* recruited 44 kids, whose average age was 12 ± 2 years to ascertain the frequency of BVA in children with and without dyslexia at the Aminu Kano Teaching Hospital (AKTH) Eye Clinic in Northern Nigeria. They reported that visual symptoms were more common in dyslexic children than non-dyslexic children [3]. Visual distortion, hazy vision, and eye discomfort were the most prevalent symptoms of BV. The most prevalent binocular vision defect was accommodative insufficiency, which was considerably more prevalent in dyslexic children (45.5%) than in non-dyslexic ones (18.2%) [3]. Ovenseri-Ogbomo & Eguegu investigated first-year university students' vergence findings and horizontal vergence dysfunction in Benin City, Nigeria in order to document the metrics that define the visual system's vergence and to determine how common vergence dysfunctions are in the research population. Their finding showed that convergence insufficiency

was the most occurring vergence dysfunction, which affected 12.7% of first-year students. Headache, diplopia, and blurred vision were the visual symptoms that people reported the most [22].

4. Discussion

4.1. Burden of binocular vision anomalies

According to a comprehensive clinical study conducted in North America, binocular and accommodative abnormalities are the most occurring eye problems in the juvenile patients apart from refractive error. Accommodative and binocular vision issues were ten times more common than other eye conditions [4]. Several investigations aimed to determine which kind of binocular vision abnormalities were most common in each research population, convergence insufficiency with a prevalence of 27.5% was the most prevalent problem identified in Mangalore, India [12] and southern India [14], as well as the second most prevalent type of binocular vision defect in Maharashtra, India, and Nepal [13, 16]. According to Dahal *et al.* [8], the most prevalent non-strabismic binocular visual impairment in Nepal was accommodative insufficiency (NSBVD), with prevalence rate of 12.85%, followed by convergence insufficiency at 11.42%. This finding aligns with other studies indicating that in people who are not presbyopic, insufficiency of accommodation is the most occurring accommodative dysfunction particularly among school-aged children. According to a study conducted in Mangalore, India, 76.5% of students have NSBVD [12], the most common condition were accommodative insufficiency (22.5%), convergence excess (24%) and convergence insufficiency (27.5%). However, in contrast to above studies, with a prevalence of 18.8%, Alghamdi *et al.* [15] discovered that accommodative excess was the most prevalent kind. Additionally, accommodative excess was reported as the second most prevalent kind BVA by Atiya *et al.* [14]. Several research used gender-based analysis to ascertain whether gender and binocular vision abnormalities are related. Females were more likely than males to have binocular vision abnormalities, according to Mondal's study conducted in Mangalore, India [12].

4.2. Types of binocular vision anomalies

4.2.1. Non-strabismic binocular vision anomalies (NSBVA)

These abnormalities, which include vergence and accommodative issues, have a functional basis and can lead to challenges in near tasks such as writing and reading. There are seven types of vergence anomalies having functional origin, and they include; basic esophoria, basic exophoria, convergence excess, divergence excess, convergence insufficiency, and fusional vergence dysfunctions. Accommodative insufficiency, accommodative infacility (accommodative inertia), and accommodative excess (accommodative spasm) are the three primary categories in accommodative abnormalities. In terms of functionality, pseudo-convergence insufficiency is a frequently documented interplay between accommodative and convergence insufficiency. Vergence anomalies, such as divergence paralysis, convergence paralysis, and convergence spasm and accommodative paralysis (subtype of accommodative insufficiency) are not functional in nature and have underlying causes of systemic illnesses. Systemic convergence dysfunction is the term used to describe the non-functional link between accommodative and convergence insufficiency and it is linked to subnormal accommodation. The indicators clinically and the underlying cause, regardless of whether it is functional or non-functional, are used to categorize non-strabismic binocular vision abnormalities [20].

4.2.2. Strabismic binocular vision anomalies (SBVA)

These anomalies are characterized by misalignment of the eyes and can lead to double vision. Various types of SBVA include; inward turning of one eye (esotropia), outward turning of one eye (exotropia), upward turning of one eye (hypertropia), or downward turning of one eye (hypotropia).

4.2.3. Other binocular vision anomalies

Other binocular vision anomalies includes; amblyopia (lazy eye), aniseikonia (a condition where the images from the two eyes are of different sizes), heterophoria (misaligned of the eye, but controlled by the visual system), diplopia (double vision), and suppression, which prevents double vision by making the brain ignore the image from one eye.

4.3. Clinical implications, symptoms, diagnosis and management of binocular vision anomalies

Binocular vision abnormalities can significantly hinder a child's ability to study and complete schoolwork. Parents frequently complain that their exceptionally intelligent children either shun schooling or simply cannot keep up with it. Binocular vision abnormalities can cause symptoms such as headaches, nausea, dizziness, unsteadiness when walking, anxiety, and difficulty focusing near tasks, reading comprehension difficulties, sleep disturbance, double vision and motion sickness. In most cases, binocular vision dysfunction may be mistakenly labeled as attention-deficit disorder (ADD) or attention-deficit hyperactivity disorder (ADHD). This may negatively impact visual function, resulting in decreased visual acuity, difficulties perceiving depth, and poor performance in tasks that require good binocular vision. Wajuihian found that the symptoms of uncorrected astigmatism and hyperopia can mimic the symptoms of accommodative disorders and convergence insufficiency [23]. Similarly, Scheiman and Wick reported that patients

with refractive errors have also been found to mimic binocular vision dysfunction [4]. Based on these findings, correcting existing ametropia is the first line of treatment for binocular vision disorders [24].

Tonic-Adie's pupil, meningitis, syphilis, malaria, anemia, mumps, measles, diabetes mellitus, multiple sclerosis, and other infectious diseases that impact the eyes and body have been shown to change the parasympathetic pathway and interfere with the accommodative system [25]. It has also been demonstrated that certain drugs, including stimulants, cycloplegics, antihistamines, and phenothiazine, affect the accommodative and vergence systems of the eyes [26]. According to Scheiman and Wick, patients with refractive issues can potentially mimic binocular vision impairment [4]. Wajuihian reported that the signs of accommodative anomalies and convergence insufficiency can be confused with those of untreated hyperopia and astigmatism [23]. Although binocular vision impairments are often associated with refractive defects, effective ametropia correction will produce typical values for accommodation and vergence [27]. To probe the accommodative system, tests such as accommodative amplitude (AA), positive relative accommodation (PRA), negative relative accommodation (NRA), monocular estimation method (MEM), and facility of accommodation tests (both binocular—BAF and monocular—MAF), as well as the vergence system, such as the positive fusional vergence (PFV), negative fusional vergence (NFV), near point of convergence (NPC), and von Graefe to assess phoria findings, are among the battery of investigations conducted to assess the binocular vision status of the patient [28].

Treatment for binocular vision anomalies can involve visual therapy, corrective lenses (glasses or contact lenses), prisms, or, in some cases, surgery, depending on the specific condition and severity. Refractive errors (nearsightedness, farsightedness, and astigmatism) that cause or mimic binocular vision dysfunction (BVD) should be appropriately corrected with glasses. Prisms are glasses which may help correct eye alignment and reroute light, especially when strabismus or other misalignment problems are present. A vision therapy treatment plan includes both office-based and home-based training sessions after ametropia correction [29]. It entails a number of ocular-exercises intended for enhancement of eye motility and coordination, muscle strength, and eye-brain connection [30]. Strabismus surgery aims to correct misaligned eyes (strabismus) by repositioning the eye muscles and adjusting the eyes by extending, shortening, or shifting extraocular eye muscle(s) [28]. Minimally invasive strabismus surgery (MISS), which makes fewer incisions compared to traditional procedures, offers an alternative. Strabismus surgery can improve eye alignment and restore binocular vision but does not eliminate the necessity for children to wear spectacles [31].

Other treatment options include Botox injections (Botulinum toxin treatment for strabismus in adults older than twelve years) [32]. The stronger muscle receives an injection of the toxin, which temporarily paralyzes it. It has been discovered that botulinum toxin injection gives similar successful outcomes as strabismus surgery except for those without binocular vision [33].

5. Conclusions

Binocular vision anomalies are vision defects that affects school age children globally with varying prevalence between 41.5% and 76.5%. While amblyopia was the most common type of strabismic binocular vision anomalies (BVAs), convergence insufficiency was the most common type of non-strabismic BVA. Headache, diplopia, and blurred vision were the visual symptoms that people reported the most, and were more common in dyslexic children than non-dyslexic children. Although, several studies demonstrated significant relationship between refractive errors and BVA, the precise proportion of those with refractive error who also have binocular vision abnormalities was not disclosed in most of these investigations. Therefore, we recommend that future studies should be conducted to reveal the proportion of subjects with refractive errors who also have binocular vision anomalies. Furthermore, this review emphasizes the necessity of conducting a comprehensive evaluation of binocular vision status of children as prerequisite for admittance of students into schools.

Data availability

Data will be made available on request.

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