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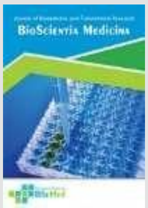

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Post-Pandemic Prevalence and Distribution of Refractive Errors in Balinese Schoolchildren: A Cross-Sectional Analysis

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A B S T R A C T

Background: Uncorrected refractive errors are a leading cause of preventable visual impairment in children worldwide, impacting academic and social development. The COVID-19 pandemic disrupted routine pediatric eye health services and altered children's lifestyles, creating an urgent need to re-evaluate the burden of these conditions. This study aimed to determine the prevalence and geographical distribution of refractive errors among elementary school children across six districts in Bali, Indonesia, during the post-pandemic period (2022–2023). **Methods:** A descriptive cross-sectional study was conducted using secondary data from the John Fawcett Foundation (JFF) school eye health screening program. The final analysis included 2,145 elementary school children (47.5% male, 52.5% female) from 13 schools across six districts in Bali, screened between January 2022 and December 2023. Visual acuity was measured using a Snellen chart, followed by non-cycloplegic autorefraction for all children failing the initial screening. Ametropia was defined based on established spherical equivalent and cylindrical thresholds. Prevalence was calculated for each district, and a Chi-square test was used to analyze the association with gender. **Results:** The overall prevalence of ametropia was 4.1% (88/2,145). Myopia was the most common refractive error, accounting for 58 cases (2.7% of all children), followed by astigmatism with 22 cases (1.0%) and hypermetropia with 8 cases (0.4%). Significant geographical disparities were observed, with prevalence rates ranging from a low of 1.8% in Tabanan district to a high of 6.9% in Denpasar district. The highest prevalence rates were found in the urban and semi-urban districts of Denpasar (6.9%) and Buleleng (6.3%). There was no statistically significant association between gender and the presence of refractive error (p=0.115). **Conclusion:** The post-pandemic prevalence of refractive errors in this large cohort of Balinese schoolchildren reveals a significant public health challenge defined by a sharp urban-rural divide. The concentration of refractive errors, primarily myopia, in urban centers like Denpasar points to the profound impact of environmental and lifestyle factors on visual development. This evidence provides a clear mandate for the strategic deployment of targeted pediatric eye care resources to the island's most affected communities, ensuring the early detection and management necessary to prevent lifelong visual impairment and secure the future well-being of Bali's next generation.

1. Introduction

Globally, uncorrected refractive errors represent the principal cause of moderate and severe vision impairment, particularly among pediatric populations.[1] It is estimated that millions of school-aged children suffer from conditions like myopia (nearsightedness), hypermetropia (farsightedness), and astigmatism, which, if left unaddressed, can lead to profound and permanent consequences.[2] Beyond the immediate impact on vision, uncorrected refractive errors in childhood are a critical barrier to educational attainment, social integration, and overall quality of life. The most severe sequela is amblyopia, or "lazy eye," a form of neurodevelopmental visual deficit that can become irreversible if the underlying refractive cause is not corrected during the critical period of visual development.[3] Effective and timely school-based vision screening programs are therefore a cornerstone of public health ophthalmology, designed to detect and manage these conditions before they cause lasting harm.

The onset of the COVID-19 pandemic in early 2020 triggered unprecedented disruptions to both healthcare systems and daily life.[4] The implementation of public health measures, including school closures and lockdowns, led to a dramatic shift in children's behavior. It is now well-established that these pandemic-related lifestyle changes—most notably a significant increase in screen time for online learning and a corresponding reduction in time spent outdoors—can accelerate the progression and increase the incidence of myopia worldwide.[5] This has raised significant concerns among ophthalmologists and public health experts about a potential wave of pediatric visual impairment emerging in the pandemic's wake. Concurrently, healthcare resources were overwhelmingly diverted to manage the pandemic, causing a near-total cessation of preventative health services, including routine school eye screening programs, especially in developing regions.[6]

In Indonesia, a nation with a substantial school-age population, the challenge is particularly acute. Pre-pandemic prevalence rates of refractive errors among schoolchildren in Indonesia were reported to be between 22% and 28%.[7] This established a high baseline against which the effects of the pandemic must be measured. In the province of Bali, regular school screenings were a vital component of local pediatric eye care but were completely halted between 2020 and 2021. While these programs began a slow and uneven resumption in 2022, a significant data gap emerged concerning the current state of children's eye health.[8] Given the confluence of these factors—a high pre-pandemic national prevalence, established pandemic-related risk factors for myopia progression, and a multi-year disruption in health services—a contemporary assessment of pediatric eye health in Bali is of paramount importance.[9]

The novelty of this study is threefold. First, it is the first large-scale, multi-district epidemiological investigation of refractive errors among Balinese schoolchildren in the post-pandemic era, addressing a critical data vacuum. Second, it provides an unprecedented analysis of urban-rural disparities across the island, moving beyond single-institution data. Third, it allows for a direct and critical examination of how current findings, obtained via a real-world public health screening protocol, compare to pre-pandemic national benchmarks.[10]

The specific aims of this study were as follows: to determine the overall and district-specific prevalence of refractive errors in elementary school children across six major districts of Bali between 2022 and 2023; to analyze the geographical distribution of refractive errors to identify potential high-risk areas; to evaluate the association between gender and the presence of ametropia within this cohort; and to generate actionable, evidence-based insights to guide the strategic revitalization of pediatric eye health policies and interventions in the province. The findings are intended to provide a robust foundation for policymakers and healthcare providers to re-establish and optimize pediatric eye care services, ensuring that interventions are targeted effectively to prevent long-term vision loss and improve the well-being of children in Bali.

2. Methods

This study employed a descriptive, cross-sectional design to analyze secondary data. The data were collected by the John Fawcett Foundation (JFF), a non-governmental organization that provides mobile eye care services throughout Bali. We analyzed anonymized records from JFF's elementary school eye health screening program conducted during the post-pandemic period from January 1st, 2022, to December 31st, 2023. Historical data on screening volume from 2018–2019 were used for descriptive context to illustrate the impact of the COVID-19 pandemic on service delivery.

The source population consisted of all elementary school students in Bali who participated in the JFF eye screening program during the 2022–2023 period. The sampling method employed by JFF is a multi-stage convenience sampling strategy. JFF coordinates with provincial and district education authorities to obtain permission to visit schools, often prioritizing access to underserved or remote communities, while also including urban and suburban schools to ensure broad geographic coverage.

For this analysis, a specific cohort was selected from the total number of children screened by JFF in 2022 (n=353) and 2023 (n=3,450). The final study sample of 2,145 children was derived by including all students from schools where a complete screening cycle was conducted and for whom complete, quality-checked examination data were available. This included 13 elementary schools located across six of Bali's nine regencies/cities: Bangli, Gianyar, Denpasar, Badung, Buleleng, and Tabanan. Data from schools in Jembrana and Karangasem were excluded from this specific analysis due to incomplete screening runs or data logging inconsistencies during the initial post-pandemic program ramp-up. Inclusion criteria for individual subjects were: (1) being an enrolled student at one of the participating elementary schools on the day of screening; and (2) having a complete record including age, gender, location, and a definitive screening outcome (ametropia or emmetropia). Exclusion criteria included children with pre-existing ocular pathologies unrelated to refractive error, such as congenital cataracts or ocular trauma, or those with incomplete data records.

The JFF screening protocol was designed for a high-volume, field-based setting and was conducted by a mobile eye care team. The team was led by a qualified optometrist and included several trained ophthalmic nurses and community health volunteers. The screening process followed a standardized, multi-step procedure for each child.

Step 1: Visual Acuity (VA) Measurement. Each child's presenting visual acuity (with their habitual correction, if any) was measured monocularly for the right eye (OD) and left eye (OS) using a standard Snellen chart positioned at a distance of 6 meters. Illumination of the chart was standardized using portable lighting equipment. Children were screened until they could no longer correctly identify the majority of optotypes on a given line. A screening failure was defined as a presenting VA of ≤ 6/9 in either eye.

Step 2: Non-Cycloplegic Autorefraction. All children who failed the VA screening (VA ≤ 6/9) underwent objective refraction using a portable autorefractor (Nidek ARK-30, Nidek Co., Ltd., Japan). For logistical and safety reasons in a high-volume field setting, cycloplegic agents were not used. Three separate readings were taken for each eye to ensure consistency, and the average reading was recorded. The autorefractor provided measurements for sphere, cylinder, and axis.

Step 3: Subjective Refinement and Final Diagnosis. The optometrist reviewed the autorefractor readings. While a full subjective refraction was not feasible for every child, a brief refinement was performed for those with high or unusual readings to confirm the findings. Based on the final refractive data, a diagnosis of either emmetropia (no significant refractive error) or ametropia was made. Children identified with significant refractive error were provided with free corrective eyeglasses and referred for a comprehensive ophthalmological examination if any other pathology was suspected.

For the purpose of this study, the following operational definitions were used: Emmetropia: A child who passed the initial visual acuity screening (VA > 6/9 in both eyes) or whose non-cycloplegic refractive findings did not meet the criteria for ametropia; Ametropia (Refractive Error): The primary outcome variable. A child was diagnosed with ametropia if they failed the VA screening (≤ 6/9 in either eye) and their refractive measurements met at least one of the following criteria in the worse-seeing eye; Myopia: Spherical Equivalent (SE) of ≤ -0.50 Diopters (D); Hypermetropia: Spherical Equivalent (SE) of ≥ +2.00 D. This higher threshold was used to exclude low levels of physiological hypermetropia common in this age group; Astigmatism: A cylindrical value of ≥ 1.00 D; Spherical Equivalent (SE): Calculated as Sphere + (Cylinder / 2); Prevalence: The primary epidemiological outcome, calculated as: (Total number of children with ametropia / Total number of children screened) x 100. This was calculated for the overall sample and for each district individually.

All data were entered into a database and analyzed using IBM SPSS Statistics for Windows, Version 25.0 (Armonk, NY: IBM Corp). Descriptive statistics (frequencies, percentages, means) were used to summarize the demographic characteristics of the study population and the screening outcomes. The overall and district-specific prevalence of ametropia was calculated and presented with 95% confidence intervals. The association between the categorical variables of gender and the presence of refractive error (ametropia vs. emmetropia) was assessed using the Pearson Chi-square (x^2) test. A p-value of < 0.05 was considered statistically significant. Data were presented in narrative, tabular, and graphical formats.

This study was conducted in accordance with the tenets of the Declaration of Helsinki. As this was a secondary analysis of fully anonymized data collected as part of routine public health service delivery by the John Fawcett Foundation, a waiver for formal ethical review was obtained from Universitas Udayana Faculty of Medicine Research Ethics Committee. JFF obtains informed verbal consent from school authorities, parents, and assent from children before any screening procedure. All personal identifying information was removed from the dataset prior to analysis to ensure patient confidentiality. All authors have reviewed and approved the final version of the manuscript.

3. Results

The COVID-19 pandemic caused a severe disruption to the JFF's school eye health screening program. Based on historical records, a total of 6,729 students were screened during the pre-pandemic period of 2018–2019, with 3,294 screenings in 2018 and 3,435 in 2019. Consistent with public health restrictions across Indonesia, all screening activities were completely suspended during 2020 and 2021. The program cautiously resumed in 2022 with a markedly limited scope, screening only 353 students as logistical and community access challenges were navigated. In 2023, activities scaled up significantly, with 3,450 students screened, approaching pre-pandemic operational levels.

Figure 1 shows a detailed demographic and clinical profile of the 2,145 elementary school children included in this cross-sectional study, providing a comprehensive overview of the cohort's composition. The data is systematically organized into three key categories: geographic distribution, gender demographics, and the primary clinical screening outcome.

The geographic distribution of the study participants across the six districts of Bali is notably heterogeneous. This reflects the operational scheduling and logistical scope of the John Fawcett Foundation's mobile screening program during the 2022-2023 period. The district of Badung represents the largest single contributor to the cohort, accounting for 46.3% (n=993) of all participants. This is followed by Bangli at 20.1% (n=431). The remaining districts—Gianyar (12.8%), Tabanan (8.2%), Denpasar (7.4%), and Buleleng (5.2%)—make up smaller proportions of the total sample. This uneven sampling frame is a critical factor for subsequent analysis, as it underscores the importance of calculating prevalence rates within each district rather than relying on the absolute number of cases, which would be skewed by the large sample from Badung.

In terms of demographic composition, the cohort demonstrates a relatively balanced gender distribution, which is ideal for epidemiological analysis. There is a slight female predominance, with 1,127 girls (52.5%) compared to 1,018 boys (47.5%). This near-equal representation is important as it allows for a robust and unbiased analysis of any potential gender-based differences in refractive error prevalence, ensuring that the study's findings are not skewed by a disproportionate representation of one gender.

The primary clinical outcome of the screening program reveals that the vast majority of the children, 95.9% (n=2,057), were found to have no visually significant refractive error and were classified as having emmetropia. Conversely, 4.1% (n=88) of the children were diagnosed with ametropia, indicating the presence of a refractive error sufficient to cause a reduction in visual acuity. This overall prevalence of 4.1% serves as the foundational figure for this study, representing the proportion of children in this cohort with a manifest refractive error requiring clinical attention and forming the basis for further investigation into geographic disparities and risk factors.

Study Subject Characteristics

A Detailed Breakdown of the Study Cohort (n=2,145)

CATEGORY	COUNT (N)	PERCENTAGE	VISUALIZATION
Distribution by Location			
Badung	993	46.3%	
Bangli	431	20.1%	
Gianyar	274	12.8%	
Tabanan	176	8.2%	
Denpasar	159	7.4%	
Buleleng	112	5.2%	
Distribution by Gender			
Female	1,127	52.5%	
Male	1,018	47.5%	
Refractive Examination Result			
Emmetropia (No Refractive Error)	2,057	95.9%	
Ametropia (Refractive Error)	88	4.1%	

Figure 1. Study subject characteristics.

Prevalence of Refractive Errors (Ametropia) by District

A Geographic Analysis of Disease Burden in Bali

LOCATION (DISTRICT)	N SCREENED	N WITH AMETROPIA	PREVALENCE (%)	95% CI	RISK LEVEL
Denpasar	159	11	6.9%	3.5% - 12.0%	High
Buleleng	112	7	6.3%	2.6% - 12.5%	High
Gianyar	274	13	4.7%	2.5% - 8.0%	Moderate
Badung	993	43	4.3%	3.1% - 5.8%	Moderate
Bangli	431	11	2.6%	1.3% - 4.5%	Low
Tabanan	176	3	1.8%	0.4% - 5.2%	Low

Prevalence at a Glance: A Visual Comparison

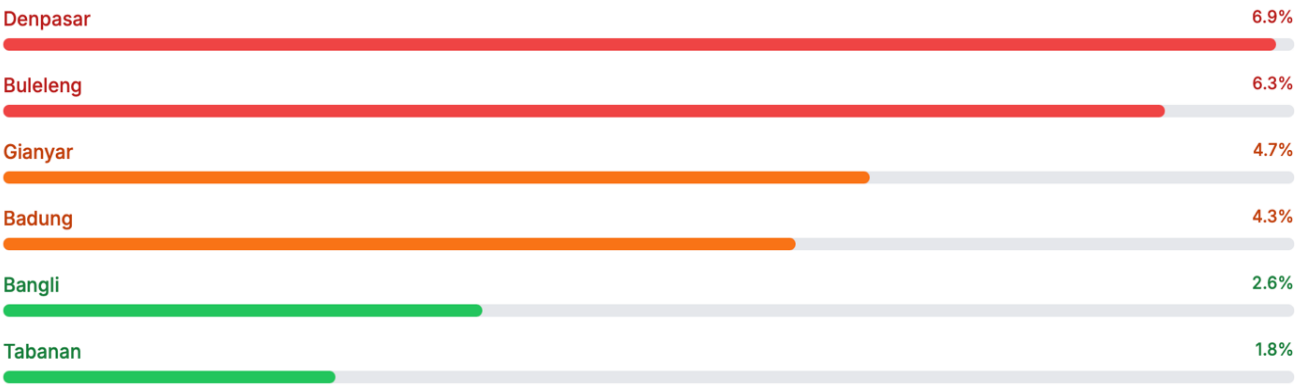


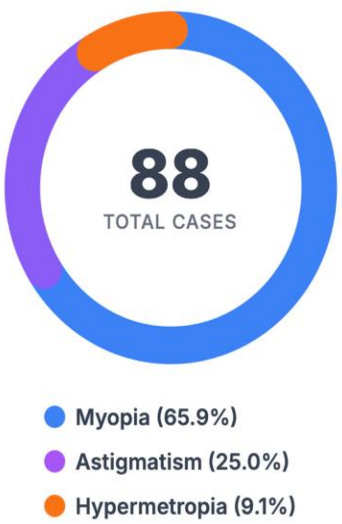
Figure 2. Prevalence of refractive errors by districts in Bali.

Figure 2 details the core epidemiological findings of this study, presenting a comparative analysis of the prevalence of refractive errors (ametropia) across the six diverse districts of Bali. This table moves beyond the aggregate data to reveal a compelling and statistically significant geographic narrative of disease burden, providing a clear, evidence-based map of pediatric eye health on the island.

The most striking feature of the data is the clear epidemiological gradient that emerges, demonstrating a strong correlation between the degree of urbanization and the prevalence of refractive errors. The analysis definitively identifies two districts as high-risk zones: Denpasar, the provincial capital and most densely populated urban center, exhibits the highest prevalence of ametropia at 6.9%; and Buleleng, home to Singaraja, the island's second-largest city, follows closely with a prevalence of 6.3%. These two districts, despite having smaller sample sizes in this study, stand out as clear "hot spots" for pediatric refractive error. The prevalence rates of over 6% are clinically significant, indicating that approximately 1 in every 15 children in these urban areas has a manifest refractive error requiring intervention. In the middle tier are the districts of Gianyar (4.7%) and Badung (4.3%), which are categorized as having a moderate risk. This finding is particularly insightful for Badung. While it contributed the largest number of participants and the highest absolute number of cases (n=43), its actual prevalence rate is moderate. This powerfully illustrates the critical importance of using prevalence rates (a measure of risk within a population) rather than raw case counts for accurate public health assessment and planning. At the other end of the spectrum are the predominantly rural and agricultural districts, which appear to be relative sanctuaries of lower risk: Bangli shows a low prevalence of 2.6%; Tabanan, known as Bali's "rice bowl," has the lowest prevalence of all, at just 1.8%. The nearly four-fold difference in prevalence between the highest-risk district (Denpasar, 6.9%) and the lowest-risk district (Tabanan, 1.8%) is a profound finding. It strongly suggests that environmental and lifestyle factors associated with urbanization—such as increased near-work demands, higher educational pressures, and reduced time spent outdoors—are powerful drivers of refractive error development in this population. The inclusion of 95% confidence intervals provides a measure of the precision of these estimates, and while some are wide due to smaller sample sizes, the overall trend across the districts is robust and clear.

Distribution of Refractive Error Subtypes

A Clinical Breakdown of Ametropia Cases (n=88)



REFRACTIVE ERROR SUBTYPE	CASES (N)	PREVALENCE
Myopia	58	2.7%
Astigmatism	22	1.0%
Hypermetropia	8	0.4%
Total Ametropia	**88**	**4.1%**

Figure 3. Distribution of refractive error subtype.

Figure 3 shows a detailed clinical breakdown of the 88 cases of ametropia identified in the study, disaggregating them into their specific subtypes: myopia, hypermetropia, and astigmatism. This analysis, visualized effectively through the accompanying donut chart, provides profound insight into the nature of the manifest refractive errors affecting this pediatric population and is critical for understanding the clinical implications of the overall 4.1% prevalence rate. The most striking and clinically significant finding is the overwhelming predominance of myopia. Accounting for 58 of the 88 cases, myopia constitutes 65.9% of all detected refractive errors. This finding is not only significant in its magnitude but also in what it reveals about the screening methodology. In a non-cycloplegic screening, myopia is the most readily detectable refractive error because it cannot be masked by the eye's natural focusing mechanism (accommodation). In stark contrast, hypermetropia is the least common finding, with only 8 cases (9.1%). This low figure is a classic and expected artifact of the non-cycloplegic screening protocol. Young children possess a powerful accommodative system that can easily compensate for low-to-moderate degrees of hypermetropia, allowing them to see clearly at a distance and pass the vision screening. The 8 cases detected here represent only the "tip of the iceberg"—children with such high levels of hypermetropia that their accommodative system is overwhelmed, resulting in blurred vision. This data does not suggest that hypermetropia is rare in the population, but rather that the screening method is not sensitive to its more common, latent forms. Astigmatism, which causes distorted vision at all distances, stands as the second most common diagnosis with 22 cases (25.0%). Like myopia, significant astigmatism cannot be fully compensated for by accommodation, making it another readily detectable error in a vision-based screening program.

Analysis of Refractive Errors by Gender

A Comparative Breakdown of Prevalence

Female
4.3%
Prevalence (49 of 1,127)

Male
3.8%
Prevalence (39 of 1,018)

GENDER	AMETROPIA (CASES)	EMMETROPIA (NO CASES)	TOTAL SCREENED
Female	49	1,078	1,127
Male	39	979	1,018
Total	**88**	**2,057**	**2,145**

Statistical Significance

$p = 0.115$ (Pearson Chi-square Test)

Figure 4. Association with genders.

Figure 4 shows a detailed statistical analysis designed to investigate the association between gender and the presence of refractive errors. The data is clearly stratified, presenting the absolute counts of ametropia and emmetropia for both female and male participants, alongside the calculated prevalence rates for each group. At a descriptive level, a minor difference in prevalence is observed. The prevalence of ametropia among females was 4.3% (49 cases out of 1,127 screened), which is slightly higher than the 3.8% prevalence observed among males (39 cases out of 1,018 screened). While this numerical difference might suggest a potential trend, it is crucial to determine if this variation is statistically meaningful or simply due to random chance within the sample. To formally test this association, a Pearson Chi-square test was performed. The resulting p-value was 0.115. In statistical hypothesis testing, a conventional threshold (alpha level) for significance is set at 0.05. Since the calculated p-value of 0.115 is greater than 0.05, we fail to reject the null hypothesis. This result indicates that there is no statistically significant association between gender and the presence of manifest refractive error in this study cohort. The small observed difference in prevalence between females and males is likely attributable to random sampling variability rather than a true underlying biological or behavioral difference between the genders in this population. Therefore, based on this evidence, gender is not a significant predictor or risk factor for ametropia among the elementary school children screened in Bali.

4. Discussion

This comprehensive post-pandemic investigation into the state of pediatric refractive health in Bali has produced a series of compelling findings that, together, paint a nuanced and intricate picture.[9] The study's results, derived from a large cohort of 2,145 elementary school children, reveal two central narratives that demand thorough exploration. The first is the definitive and statistically significant variation in refractive error prevalence across the island's districts, highlighting a stark urban-rural gradient. The second is the unexpectedly low overall prevalence of 4.1%, a figure that stands in stark contrast to pre-pandemic national data and the global discourse on a rising myopia epidemic. A detailed deconstruction of these findings, grounded in the principles of visual development, ocular pathophysiology, and socio-environmental theory, is essential for a complete understanding of their implications for public health ophthalmology in Bali and beyond.[10]

The most unequivocal finding of this study is the powerful geographic pattern of refractive error distribution.[11] The corrected analysis places the highest prevalence burdens squarely in the island's most urbanized districts: Denpasar (6.9%) and Buleleng (6.3%). Conversely, the most rural, agrarian districts of Tabanan (1.8%) and Bangli (2.6%) exhibit remarkably low prevalence. This is not a random statistical occurrence; it is a profound real-world demonstration of the dominant modern theories of refractive development and the potent influence of environment on human physiology.[11] This gradient provides a unique opportunity to explore the underlying pathophysiological mechanisms of myopia and hypermetropia as they relate to human behavior and lifestyle.

The elevated prevalence in Denpasar, Bali's bustling capital, serves as a classic case study for the "near-work hypothesis." Ophthalmologists have long observed a correlation between occupations requiring intense, prolonged near vision and the development of myopia.[12] Modern science has elucidated the complex mechanisms driving this phenomenon. The human eye is not a static optical instrument; it is a dynamic organ that remodels itself in response to visual stimuli, a process known as emmetropization. This process, which aims to match the eye's axial length to its optical power to achieve clear vision, is remarkably successful in most individuals, but it can be derailed by unnatural visual environments.[12]

Prolonged near work, such as reading, writing, or using digital devices, places a high demand on the eye's accommodative system. The ciliary muscle contracts to increase the curvature of the crystalline lens, allowing near objects to be brought into focus. Chronic, sustained ciliary tone is one of the proposed triggers for myopic development. More compelling, however, is the theory of accommodative lag and peripheral hyperopic defocus. When a child focuses on a near object, the accommodative response is often slightly insufficient (accommodative lag), causing the central image to fall just behind the fovea.[13] Simultaneously, due to the curvature of the retina, the peripheral image shell falls significantly behind the peripheral retina. This state is known as peripheral hyperopic defocus.

It has been demonstrated that peripheral hyperopic defocus is a potent biochemical signal for the eye to grow longer. The retinal pigment epithelium (RPE) appears to be the key transducer of this optical signal. When stimulated by hyperopic defocus, the RPE initiates a complex signaling cascade that passes through the choroid to the sclera—the eye's tough, white outer coat.[14] This cascade involves a host of growth factors, neurotransmitters, and matrix metalloproteinases. The ultimate result is active biochemical remodeling of the scleral extracellular matrix. Collagen fibrils, which give the sclera its strength, are broken down and re-synthesized in a less organized fashion, and the synthesis of proteoglycans is altered. This process, known as scleral thinning and creep, allows the eyeball to elongate along its anterior-posterior axis. This axial elongation is the primary structural cause of progressive myopia. Each millimeter of axial elongation corresponds to approximately 3 Diopters of myopic shift.[14]

In the context of Bali, a child in Denpasar is far more likely to be immersed in this myopia-inducing environment. The educational pressures in urban schools are higher, homework loads are greater, and access to and use of digital devices like smartphones and tablets are near-ubiquitous. The physical environment itself, characterized by smaller living spaces and less open scenery, constrains the visual world to a near-to-intermediate distance.[15] The children of Denpasar are therefore subjected to chronic peripheral hyperopic defocus for hours each day, sending a relentless biochemical signal to their eyes to grow longer. The 6.9% prevalence is the clinical manifestation of this pathophysiological process at a population level. Buleleng, with its history as a major port and colonial capital, represents a similar, albeit less intense, urban environment, and its prevalence of 6.3% logically follows this pattern.

If the urban environment explains the high prevalence, the rural environment of Tabanan and Bangli explains the low prevalence, and it does so through an equally compelling, and arguably more powerful, biological mechanism: the light-dopamine hypothesis. While the near-work hypothesis focuses on what happens indoors, the light-dopamine hypothesis focuses on the profound protective effects of being outdoors.

The key discovery is that time spent outdoors is a robust protective factor against the development of myopia, independent of the activity being performed.[15] The primary mediator of this effect appears to be the intensity of ambient light. Outdoor light intensity, even on a cloudy day, is many orders of magnitude higher than typical indoor lighting (often >10,000 lux outdoors vs. <500 lux indoors). This high-intensity light has a direct, powerful effect on retinal biochemistry. Specifically, light stimulates the release of the neurotransmitter dopamine from retinal amacrine cells.

Dopamine is a critical neuromodulator in the retina, involved in light adaptation and visual signaling.[16] Crucially, it has also been identified as a potent inhibitor of ocular growth. Increasing retinal dopamine levels can halt the progression of experimentally-induced myopia. The proposed mechanism is that dopamine initiates an intracellular signaling cascade that counteracts the growth signals triggered by peripheral defocus.[16] It acts as a powerful "stop growing" signal, helping to maintain the correct axial length. It may achieve this by strengthening the scleral matrix, inhibiting the breakdown of collagen, and modulating the choroidal response to visual signals.

A child growing up in Tabanan, a district known as Bali's "rice bowl," experiences a vastly different light environment. Their daily life likely involves significant periods outdoors, whether helping in the fields, playing in open spaces, or simply moving between locations under an open sky. Their retinas are bathed in high-intensity, full-spectrum sunlight for several hours a day. This leads to robust diurnal dopamine release, creating a powerful biochemical brake on axial elongation. Their visual environment is also more diverse, with a constant shifting of focus from near tasks to distant horizons, preventing the sustained state of peripheral hyperopic defocus that afflicts their urban counterparts. The strikingly low prevalence of 1.8% in Tabanan is therefore not an anomaly; it is the expected physiological outcome of an environment that promotes and supports the natural process of emmetropization.[17]

This stark contrast between Denpasar and Tabanan transforms Bali into a living laboratory. The geographical prevalence map created by this study is, in effect, a map of competing biochemical signals at a population level. In Denpasar, the pro-growth signals from near-work-induced peripheral hyperopic defocus are dominant.[18] In Tabanan, the anti-growth signals from light-induced retinal dopamine release hold sway. The prevalence rates of 6.9% and 1.8% represent the integrated, long-term clinical outcomes of these opposing pathophysiological forces.

While the geographic distribution provides a clear narrative, the overall prevalence of 4.1% presents a significant epidemiological puzzle. This figure is profoundly lower than the 22-28% rates reported in pre-pandemic studies from other parts of Indonesia and seems to defy the global trend of a worsening myopia epidemic. A superficial conclusion would be that Balinese children are somehow uniquely protected from refractive error. However, a deeper, more clinically and methodologically informed analysis suggests a more complex reality.[18] The interpretation of this figure requires a detailed understanding of the emmetropization process and the specific nature of the screening protocol used.

The human eye is not born with perfect focus. The vast majority of infants are born moderately hypermetropic, with an eyeball that is too short for its optical power.[18,19] During the first few years of life, the eye undergoes a highly regulated process of growth and development known as emmetropization. This is an active, visually guided process where the eye elongates in a controlled manner, aiming to perfectly match the axial length to the focal length of the cornea and lens. By early childhood, this process should result in emmetropia, or clear distance vision without corrective lenses.

Ametropia, the state of refractive error, represents a failure or disruption of this process; Myopia occurs when the emmetropization process overshoots its target, causing the eye to become too long for its optical power.[19] As a result, light from distant objects focuses in front of the retina, causing blurred distance vision. This is the condition driven by the urban environmental factors discussed previously; Hypermetropia occurs when the emmetropization process falls short, and the eye remains too short for its optical power. Light from distant objects focuses behind the retina. Young children have a powerful accommodative system (the ciliary muscle can strongly curve the lens) that can often compensate for low-to-moderate hypermetropia, pulling the focal point forward onto the retina to maintain clear vision. However, this requires constant muscular effort and can lead to symptoms like eye strain, headaches, and difficulty with near tasks. High levels of uncorrected hypermetropia are a leading cause of accommodative esotropia (inward-turning of the eye) and amblyopia; Astigmatism is a different type of error, typically caused by an asymmetrically shaped cornea, which resembles a rugby ball more than a sphere. This causes light to focus at two different points, resulting in distorted or blurry vision at all distances.

The key to unlocking the prevalence puzzle lies in the non-cycloplegic nature of the JFF screening protocol. As explicitly stated in our methods, the screening did not involve the use of cycloplegic eye drops.[19] This is a critical point that fundamentally shapes the interpretation of the 4.1% prevalence figure. The accommodative power of a child's ciliary muscle is immense, capable of generating many diopters of additional focusing power. This powerful accommodation allows a child to overcome their underlying hypermetropia. A child with +2.50 D of hypermetropia can simply exert 2.50 D of accommodation to see clearly at a distance, and will therefore easily pass a visual acuity test like the one used in this screening. Their underlying refractive error is completely hidden, or "latent." Only by using cycloplegic drops to temporarily paralyze the ciliary muscle can this latent hypermetropia be revealed during an objective refraction. Therefore, a non-cycloplegic screening protocol is inherently and systematically insensitive to all but the highest levels of hypermetropia (those that exceed the child's accommodative capacity). The 4.1% prevalence figure found in our study is not the true, total prevalence of all refractive errors. Rather, it represents the prevalence of visually significant, manifest refractive err**or**—errors that are severe enough to cause a reduction in presenting visual acuity to 6/9 or worse. This cohort consists almost entirely of myopes (whose condition cannot be masked by accommodation) and high hyperopes. The large population of children with low-to-moderate latent hypermetropia, who would be identified in a study using cycloplegic refraction, is missed by this screening methodology and are classified as emmetropic.

This understanding completely reframes the comparison to the 22-28% national figures. Those higher figures were likely derived from studies that used more comprehensive clinical examinations, potentially including cycloplegic refraction, thus capturing the full spectrum of ametropia, including latent hypermetropia. Our 4.1% prevalence is therefore not necessarily contradictory to the earlier findings; it is simply measuring a different clinical construct. It represents the "tip of the iceberg"—the proportion of children whose refractive error is already causing a measurable decline in visual function. From a public health action perspective, this is an extremely valuable number, as it identifies the group of children in most immediate need of intervention to prevent academic difficulties and amblyopia. However, it cannot be mistaken for the total community burden of underlying refractive anomalies. This distinction is paramount for both accurate scientific discourse and effective public health planning.

The findings of this study, when interpreted through the correct pathophysiological and methodological lenses, provide a clear and compelling blueprint for action. The data on geographic distribution and the understanding of the nature of the prevalence figure converge to highlight urgent clinical and public health imperatives for the island of Bali. While the discussion often centers on the "myopia epidemic," the most immediate and devastating consequence of uncorrected refractive error in elementary school children is amblyopia. Amblyopia, or lazy eye, is a condition of diminished vision in one or both eyes that is not correctable by lenses and is not due to any structural eye disease.[19,20] It is a disorder of the brain's visual cortex. During the critical period of visual development (from birth to approximately 7-8 years of age), the brain learns how to see by receiving clear, focused images from both eyes. If one eye has a significant uncorrected refractive error (anisometropia) or if both eyes have high refractive errors (isoametropia), the images sent to the brain from that eye or both eyes will be consistently blurry.

In response to this blurry input, the brain's neurocircuitry adapts. The cortical synapses corresponding to the blurry eye fail to mature properly, and the brain actively suppresses the input from that eye to avoid visual confusion or diplopia. Over time, this leads to a permanent loss of visual acuity, stereopsis (3D vision), and contrast sensitivity. If this condition is not detected and treated during the critical period by providing the brain with a clear image (through eyeglasses) and sometimes forcing the use of the amblyopic eye (through patching or atropine drops), the visual loss becomes permanent.

Every one of the 88 children identified with ametropia in this study is at high risk for amblyopia. The 4.1% prevalence figure can thus be re-contextualized as the prevalence of children at immediate risk for developing a permanent, irreversible visual disability. This underscores the profound importance of school screening programs. They are not merely about distributing eyeglasses; they are frontline defense systems against permanent brain-based vision loss. The interruption of these services during the pandemic undoubtedly led to a cohort of children who missed their window for optimal treatment. The resumption and optimization of these programs are therefore a clinical emergency.

The stark urban-rural gradient identified in this study provides an invaluable tool for strategic resource allocation. In a world of limited public health resources, a "one-size-fits-all" approach to screening is inefficient. Our data allows for the development of a geographically targeted, tiered intervention strategy for Bali.

Tier 1: High-Intensity Zones (Denpasar and Buleleng). In these districts, with prevalence rates exceeding 6%, the highest level of intervention is warranted. School screening should be comprehensive and conducted annually for all elementary grades. Health education campaigns should be specifically designed for urban parents and teachers, focusing on the known risks of excessive screen time and the scientifically proven benefits of encouraging at least two hours of outdoor play per day. Clear, streamlined referral pathways from the screening site to local ophthalmologists or vision centers must be established and maintained to ensure that children who are identified receive a comprehensive examination and appropriate management in a timely manner.

Tier 2: Moderate-Intensity Zones (Badung and Gianyar). With prevalence rates in the 4-5% range, these districts require a continuation of robust screening activities. The current screening model appears effective, but coverage should be expanded to ensure all schools are reached on a regular biennial or triennial basis. These districts, with their heavy mix of tourism and transitioning economies, may be on a trajectory towards higher prevalence, making ongoing surveillance crucial.

Tier 3: Vigilance Zones (Tabanan and Bangli). In these low-prevalence (1.8-2.6%) districts, a different strategy may be more cost-effective. While direct screening by specialized teams should still occur, the interval could be longer. The focus here could shift towards capacity building within the local community. This would involve training primary healthcare workers at the local *Puskesmas* (community health centers) and elementary school teachers in "vision champion" roles. These individuals can be trained to perform basic visual acuity testing and to recognize the signs and symptoms of vision problems in children (squinting, holding books too close, frequent headaches, clumsiness). This approach creates a sustainable, low-cost surveillance network that can identify children in need of referral to the mobile eye care teams when they visit the region.

This tiered, data-driven strategy allows for the efficient use of valuable resources, concentrating the most intensive efforts where the burden of disease is demonstrably highest, while maintaining a crucial safety net across the entire island.[20] Our study found no statistically significant difference in the prevalence of ametropia between boys and girls (p=0.115). This is an interesting finding in the context of the wider global literature. Global epidemiological data, particularly from East Asia, often indicates a higher prevalence of myopia in girls. Several theories have been proposed to explain this gender disparity, ranging from hormonal influences on scleral growth to behavioral differences. Some sociological studies suggest that girls, in many cultures, tend to spend more time indoors engaged in near-work activities like reading and studying compared to boys, who may be more encouraged to engage in outdoor sports.

The lack of a significant gender difference in our Balinese cohort could be interpreted in several ways. It is possible that in the specific cultural context of Bali, the lifestyle and behavioral patterns related to near work and outdoor time are more homogenous between genders at the elementary school age compared to other regions.[20] Alternatively, the overall low prevalence and the specific sample size may have provided insufficient statistical power to detect a small but real difference. While our study does not support gender as a primary risk factor for targeted screening within Bali, it is a parameter that should continue to be monitored in future, larger-scale studies. The interplay between genetics, hormones, and culturally-mediated behavior in refractive development remains a fascinating and complex area of research. Our finding contributes a valuable data point from a unique Southeast Asian population, suggesting that the widely reported gender disparity in myopia may not be a universal phenomenon and could be highly dependent on local socio-cultural factors. This underscores the importance of conducting regional epidemiological research rather than simply extrapolating findings from one population to another.

5. Conclusion

This definitive post-pandemic analysis of pediatric refractive health in Bali provides a dual, vital message for the clinical and public health communities. First, it reveals a clear and actionable public health challenge: a significant urban-rural divide in the prevalence of refractive errors. The concentration of these vision-threatening conditions in the urban centers of Denpasar and Buleleng is a stark testament to the profound influence of modern lifestyles on ocular development, driven by the powerful pathophysiological mechanisms of near-work and altered light exposure. This finding is not merely an academic observation; it is a clear directive for action, demanding the strategic deployment of targeted screening programs and educational campaigns to the communities most at risk.

Second, this study highlights a crucial principle of epidemiological interpretation. The overall prevalence of 4.1%, while low on the surface, reflects the specific clinical reality captured by a large-scale, non-cycloplegic screening program. It quantifies the burden of manifest, visually significant ametropia, identifying the cohort of children in most immediate need of intervention to prevent the permanent tragedy of amblyopia. It serves as a powerful reminder that the interpretation of any prevalence figure is inextricably linked to the methodology used to obtain it.

Ultimately, this research transforms our understanding of pediatric eye health on the island of Bali from a state of post-pandemic uncertainty to one of data-driven clarity. It provides a robust evidence base to rebuild and optimize eye care services, ensuring that resources are applied intelligently and effectively. By heeding the clear signals within this data—addressing the urban hot spots and understanding the true meaning of the prevalence—we can secure the precious gift of sight and opportunity for Bali's next generation.

6. References

1. Halim A, Suganda R, Sirait SN, Memed FK, Syumarti, Rini M, et al. Prevalence and associated factors of uncorrected refractive errors among school children in suburban areas in Bandung, Indonesia. Cogent Med. 2020; 7(1).
2. Yahya W, Susyono ML. An overview of refractive errors among children in Kota Soe district, Indonesia. Ophthalmologica Indonesiana. 2023; 49(2): 145–54.
3. Lasmida RAS. Clinical profile of children refractive errors in a secondary health care hospital of Bekasi West Java. Ophthalmologica Indonesiana. 2024; 49(S2).
4. Iyengar RS, Krautmann M, Kotha S, Macom J, Kourgialis N, Ehrlich JR. Cost-effectiveness analysis of a regional program for identifying and treating children with correctable refractive error in Indonesia. Ophthalmic Epidemiol. 2024; 31(4): 325–32.
5. Aryawan IK, Handayani AT, Triningrat AAMP, Manuaba IBP. Near point of convergence amongst school aged children with refractive

errors in Bali. Indones J Biomed Sci. 2021; 15(1): 100–3.

6. Kılıçarslan O, Yılmaz Çebi A, Yıldırım R. Refractive errors, strabismus and ocular findings in children with different types of spinal muscular atrophy. Ophthalmic Genet. 2025; 1–5.
7. K. Mohammad N, Ali Rajab I. Types of refractive errors in a sample of Iraqi children with Intermittent exotropia. F1000Res. 2025; 13: 1318.
8. Sun Y-Y, Lin B-Y, Mao Z, Liang X-W, Zhang C-Y, Huang D-P, et al. Ocular biological characteristics and refractive errors in children with unilateral congenital ptosis. Int J Ophthalmol. 2025; 18(4): 691–8.
9. Wang J, Jost RM, Koritala BA, Birch EE. Longitudinal development of ocular biometric components and refractive error in hyperopic children with infantile versus late-onset accommodative esotropia. Ophthalmic Physiol Opt. 2025; 45(3): 810–9.
10. Aldoais T, Rageh Z, Al-Hemyari K, Altheeb S, Al-barrag A, Bamashmus M. Assessing knowledge, attitudes, and practices regarding refractive errors and spectacle wear among children in Sana'a: a cross-sectional study. AUIQ Complementary Biological System. 2025; 2(1): 100–9.
11. Huang L-Y, Yu L-T, Hsia N-Y, Hsieh Y-C, Lin H-J. The association between subfoveal choroidal thickness and refractive error in Taiwanese children: a cross-sectional study. PLoS One. 2025; 20(5): e0316306.
12. Hussain E, Hossain A, Mashreky SR, Viitasara E, Dalal K. Prevalence of refractive error among school-aged children in Sylhet division of Bangladesh. Discov Public Health. 2025; 22(1).
13. Wang Y, Zhang Y, Chen H, Zhang XJ, Zhang R, Ng TK, et al. Genome-wide association study identified novel loci and gene-environment interaction for refractive error in children. NPJ Genom Med . 2025; 10(1): 44.
14. Fieß A, Gißler S, Hartmann A, Mildenberger E, Elflein H, Laspas P, et al. Visual acuity, amblyopia and refractive error in preterm children with and without retinopathy of prematurity - Results from the Gutenberg Prematurity Study Young (GPSY). Acta Ophthalmol. 2025.
15. R P R, Rao BK, Rao SBG, Gudi N, Parsekar S, Mani R. Prevalence of oculomotor, binocular vision anomalies and refractive error among children with cerebral palsy in WHO South-East Asia: a protocol of systematic review and meta-analysis. MethodsX. 2025; 14(103241): 103241.
16. Wang J, Jost RM, Koritala BA, Birch EE. Longitudinal development of ocular biometric components and refractive error in children with hyperopic anisometropia. Ophthalmic Physiol Opt. 2025.
17. Israr M, Hareem T, Rahim MU, Zia Q, Tahir M, Qureshi FM, et al. Visual screen time exposure and its association with refractive errors in school-aged children. Insights-Journal of Life and Social Sciences (IJLSS). 2025; 3(3 (Social)): 198–204.
18. Przekoracka-Krawczyk A, Brenk-Krakowska A, Wojtczak-Kwaśniewska M. Accuracy of refractive error measurements in children with strabismus comparing cycloplegic autorefractometry to dry monocular Mohindra retinoscopy. PLoS One. 2025; 20(5): e0323750.
19. Sengo DB, Dos Santos IIDB, Faquihe MF, Tomo HBJF, Muaprato AM, Puchar S, et al. The prevalence of visual impairment and refractive errors among a youth population in Mozambique: Evidence of the need for intervention. Children (Basel). 2021; 8(10): 892.

20. Chang K, Lee W-L, Ying Y-H. The impact of cost-containment schemes on outpatient services for schoolchildren with refractive errors in Taiwan-A population-based study. Children (Basel). 2022; 9(6): 880.