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Interplay of Genetic and Environmental Factors in Myopia Progression among Elementary School Children in Jeju Island, South Korea: A Prospective Cohort Study

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ABSTRACT

Myopia has become a significant global health concern, particularly in East Asian countries. This prospective cohort study investigated the complex interplay of genetic and environmental factors in myopia progression among 425 elementary school students in Jeju Island, South Korea, over a two-year period. Ocular biometric parameters and lifestyle factors were assessed using a non-contact optical biometer and questionnaires, respectively. The study revealed that the proportion of participants using smartphones for 4 hours or more increased from 0.2% at baseline to 10.6% at the 2-year follow-up. Additionally, the mean axial length increased by 0.43 mm, and the mean emmetropic power showed a myopic shift of 1.2 D over the study period. Interestingly, the change in axial length and emmetropic power over the 2-year period showed significant correlations with time spent on after-school homework and learning, but not with parental myopia. While genetic factors, particularly parental myopia, play a role in the development of myopia, environmental factors such as extensive after-school learning may have a more significant impact on myopia progression. The findings emphasize the need for balanced lifestyles, outdoor activities, and management of near work and screen time to prevent and control myopia in school-aged children. The study has important implications for public health, education, policy development, and future research, as implementing evidence-based strategies and exploring innovative approaches can help reduce the burden of myopia and improve the visual health of future generations.

Introduction

Myopia, commonly known as nearsightedness, has become a significant global public health issue, particularly prevalent in East Asian populations. The prevalence of myopia in East Asia has reached alarming levels, with studies reporting that over 80% of young adults in urbanized regions are affected.[1] This rapid increase is often attributed to a combination of genetic predisposition and environmental factors, including extensive near work, and reduced outdoor activities.[2] The COVID-19 pandemic has further exacerbated the myopia epidemic, with increased screen time and reduced outdoor activities due to lockdowns and social distancing measures. Studies have reported a significant rise in myopia prevalence among children during the pandemic period, underscoring the urgent need for comprehensive strategies to address the growing myopia burden.[3]

One of the most significant environmental factors influencing myopia development is the amount of time spent outdoors. Numerous studies have demonstrated that increased outdoor activities are associated with a reduced risk of myopia onset and slower myopic progression. The protective effect of outdoor time is thought to be related to exposure to natural light, which may stimulate the release of dopamine in the retina, inhibiting axial elongation of the eye.[4] Conversely, increased near work and screen time have been implicated in the rising prevalence of myopia. Activities such as reading, using computers, and playing video games require prolonged focus on close objects, which can contribute to the development and progression of myopia.[5]

This study aims to investigate the ocular biometric distribution and its correlation with lifestyle factors among elementary school children in Jeju Island, South Korea. By examining the influence of outdoor activities, near work, and parental myopia on the development and progression of myopia, this research seeks to provide valuable insights into effective myopia management strategies for school-aged children. Understanding these factors is crucial for developing targeted interventions to mitigate the myopia epidemic in this vulnerable population.

Literature Review

Genetic and Environmental Factors

The etiology of myopia is complex, involving both genetic and environmental components. Studies have shown that genetic factors can explain a significant portion of the variance in refractive error within populations. For instance, Lim et al. (2018) found that parental refractive errors significantly influenced the prevalence of myopia in Korean children.[6] However, environmental factors such as near work and reduced outdoor activities have also been identified as major contributors to the recent surge in myopia cases. The interplay between these factors suggests that while genetic predispositions set the stage for myopia, environmental influences play a critical role in its progression.

Impact of Outdoor Activities

Outdoor activities have been shown to play a protective role against myopia development. Increased exposure to natural light is believed to stimulate the release of dopamine in the retina, which inhibits axial elongation of the eye. Yoo et al. (2013) reported that children who spent more time outdoors had a lower risk of developing myopia.[7] This finding is supported by numerous studies that highlight the importance of outdoor activities in mitigating myopia progression. For example, a meta-analysis by Dhakal et al. (2022) demonstrated that each additional hour spent outdoors per week was associated with a 2% reduction in the odds of developing myopia.[8]

Near Work and Screen Time

The relationship between near work, screen time, and myopia is well-documented. Activities that require prolonged focus on close objects, such as reading and using electronic devices, have been associated with an increased risk of myopia. Lee et al. (2013) found that near work was a significant risk factor for myopia in a rural Korean population.[7] The COVID-19 pandemic has further highlighted this issue, with increased screen time during lockdowns contributing to a rise in myopia prevalence among children. A study by Wong et al. (2021) reported a significant increase in myopia incidence among children during the pandemic, correlating with increased screen time and reduced outdoor activities.[9]

Machine Learning Models for Myopia Prediction

Recent advancements in machine learning have provided new tools for predicting myopia progression. Machine learning models can analyze large datasets to identify patterns and risk factors associated with myopia. These models have shown promise in accurately predicting myopia progression based on various biometric and lifestyle factors. For instance, a study by Foo et al. (2021) utilized machine learning algorithms to predict myopia progression with high accuracy, incorporating factors such as axial length, corneal curvature, and near work activities.[10] Integrating machine learning into myopia research can enhance our understanding of the condition and improve prevention strategies by identifying high-risk individuals and tailoring interventions accordingly.

Methods

This prospective cohort study was conducted to evaluate the ocular biometric distribution and its correlation with lifestyle factors among elementary school students. The study was approved by the Institutional Review Board (IRB) of the University Hospital, and informed consent was obtained from all participants and their parents.

Study Population

A total of 425 third and fourth-grade students from six elementary schools were enrolled in the study. The schools were selected based on their willingness to participate and their representation of the diverse demographic characteristics of the region, including urban and suburban areas and varying socioeconomic status of the students' families. The inclusion criteria were: (1) students enrolled in the third or fourth grade at one of the participating schools; (2) parental consent; and (3) student assent. Exclusion criteria included: (1) presence of any known ocular pathology or systemic condition that could affect the study outcomes; and (2) inability to complete the follow-up assessments.

Data Collection

Data were collected at baseline and at each follow-up assessment over a two-year period. The follow-up assessments were performed when the students reached the fifth and sixth grades. Primary outcome measures included ocular biometric factors: axial length, corneal curvature, and emmetropic intraocular lens (IOL) power calculated using the Haigis formula. Secondary outcome measures included environmental factors assessed through a questionnaire (lifestyle, TV watching time, smartphone and computer usage time, outdoor activity duration, parental myopia, and average homework time) and physical measurements (age in months, height, and body weight). Ocular biometric factors were measured using the IOL master® (Carl Zeiss Meditec AG, Jena, Germany), a non-contact optical biometer. Emmetropic IOL power, calculated using the Haigis formula, which considers axial length, corneal curvature, and anterior chamber depth, represents the intraocular lens power required to achieve emmetropia (i.e., no refractive error). The normal range for emmetropic IOL power is approximately 18-23 diopters, with an average of 20.5 diopters. Lower values (≤15 diopters) suggest a higher degree of myopia, while higher values (≥26 diopters) indicate a greater likelihood of hyperopia. Thus, emmetropic IOL power can be used as a predictive factor for refractive status in the absence of direct refractive measurements. Lifestyle factors and physical measurements were collected using a comprehensive questionnaire.

Statistical Analysis

Correlation analysis was performed to examine the relationship between ocular biometric factors and environmental factors. Statistical analyses were conducted using appropriate methods to identify significant associations and trends between the variables of interest. Data were analyzed using SPSS statistics (version 26.0, IBM, Armonk, NY, USA), and a p-value of less than 0.05 was considered statistically significant. The study aimed to provide insights into the distribution of ocular biometric factors among elementary school students and to investigate the potential influence of lifestyle factors on these parameters. The findings of this study may contribute to a better understanding of the complex interplay between environmental factors and ocular development in children.

Results

A total of 425 third and fourth-grade students from six elementary schools were enrolled in this 2-year prospective cohort study. The participants were re-evaluated when they reached the fifth and sixth grades.

Baseline Characteristics

At the initial examination, the mean age of the participants was 9 years and 11 months. The gender ratio was not recorded. The mean axial length was 23.81 ± 0.99 mm, and the mean corneal curvature was 43.15 ± 1.41 D. The mean emmetropic power was 21.01 ± 2.85 D. The questionnaire revealed that 91 (21.4%) participants had paternal myopia, and 126 (29.6%) had maternal myopia. The average time spent on after-school learning and homework was 1.96 hours, while the average time spent watching TV was 2.07 hours. The mean duration of PC use was 1.35 hours, and the average smartphone use time was 1.17 hours. The average time spent on outdoor activities was 1.96 hours. The mean height, weight, and BMI of the participants were 136.4 cm, 34.1 kg, and 18.2, respectively.

Follow-Up Examination

At the 2-year follow-up examination, the mean axial length increased to 24.25 ± 1.14 mm, and the mean corneal curvature was 43.11 ± 1.40 D. The mean emmetropic power decreased to 19.81 ± 3.38 D. The questionnaire data showed that the average time spent on after-school learning and homework increased to 2.23 hours, and the average TV watching time was 2.21 hours. The mean duration of PC use increased to 1.49 hours, and the average smartphone use time increased to 1.85 hours. The average time spent on outdoor activities increased to 2.33 hours. The mean height, weight, and BMI of the participants were 149.0 cm, 43.9 kg, and 19.6, respectively (Table 1).

Table 1. Demographic and ocular biometric characteristics of participants at initial and 2-year follow-up examinations

Characteristic	Baseline	2-Year Follow-up
Mean Axial Length (mm)	23.81 ± 0.99	24.25 ± 1.14
Mean Corneal Curvature (Diopter)	43.15 ± 1.41	43.11 ± 1.40
Mean Emmetropic Power (Diopter)	21.01 ± 2.85	19.81 ± 3.38
After-School Learning and Homework (hours)	1.96	2.23
TV Watching Time (hours)	2.07	2.21
PC Use Time (hours)	1.35	1.49
Smartphone Use Time (hours)	1.17	1.85
Outdoor Activities (hours)	1.96	2.33
Mean Height (cm)	136.4	149.0
Mean Weight (kg)	34.1	43.9
Mean BMI	18.2	19.6

Changes in Smartphone Use and Ocular Biometric Parameters

The cohort analysis revealed a substantial increase in the proportion of participants using smartphones for 4 hours or more, from 2 (0.2%) at baseline to 45 (10.6%) at the 2-year follow-up (Table 2). The mean axial length increased by 0.43 mm, and the mean emmetropic power showed a myopic shift of 1.2 D over the 2-year period.

Table 2. The smartphone use time at baseline and at the 2-year follow-up

Hour	1	2	3	4	5
Baseline (%)	87.3	9.4	2.8	0.2	0.2
2-year follow-up (%)	56	20.5	12.9	4	6.6

Correlation Analysis

Correlation analysis was performed between axial length, emmetropic power, questionnaire results, height, weight, and BMI. Correlation analysis revealed that both paternal and maternal myopia were significantly associated with axial length and low emmetropic power at the initial examination. However, at the 2-year follow-up, axial length and low emmetropic power showed significant correlations not only with parental myopia but also with time spent on after-school homework and learning.

The change in axial length over the 2-year period showed a significant correlation with time spent on after-school homework and learning, but not with paternal myopia or maternal myopia (Table 3). Furthermore, the change in emmetropic power over the 2-year period was significantly associated with paternal myopia and time spent on after-school homework and learning. TV watching time, PC use time, and smartphone use time did not show significant correlations with axial length or emmetropic power. Axial length was positively correlated with age, but keratometry did not show a significant correlation with age.

Table 3. Correlation analysis between parental myopia, time spent on after-school homework and learning, and ocular biometric parameters at initial and 2-year follow-up examinations.

Variable	Paternal Myopia (R, p)	Maternal Myopia (R, p)	After-School Study Hour (R, p)
Axial Length at Initial Examination	0.195, 0.000*	0.148, 0.002*	0.065, 0.184
Emmetropic Power at Initial Examination	-0.170, 0.000*	-0.158, 0.001*	-0.027, 0.582
Axial Length at 2-Year Follow-Up	0.198, 0.000*	0.157, 0.001*	0.185, 0.000*
Emmetropic Power at 2-Year Follow-Up	-0.243, 0.000*	-0.181, 0.001*	-0.167, 0.001*
Change of Axial Length	0.088, 0.069	-0.044, 0.371	-0.154, 0.001*
Change of Emmetropic Power	-0.164, 0.001*	-0.045, 0.355	-0.197, 0.009*

* $p<0.05$

Discussion

The high prevalence of myopia in East Asia, particularly among school-aged children, has become a significant public health concern. This two-year prospective cohort study aimed to investigate the complex interplay of genetic and environmental factors in myopia progression among elementary school children in Jeju Island, South Korea. The study included 425 children from third and fourth grades, and the findings provide valuable insights into the correlations between lifestyle factors and ocular biometric measurements.

One of the key findings of this study was the significant correlation between axial length, low emmetropic power, and parental myopia, as well as time spent on after-school homework and learning. The results suggest that while genetic factors, particularly parental myopia, play a role in the development of myopia, environmental factors such as extensive after-school learning may have a more significant impact on myopia progression. The correlation analysis revealed that both paternal and maternal myopia were significantly associated with axial length and low emmetropic power at the initial examination, indicating a genetic influence on the development of myopia. Interestingly, paternal myopia showed a slightly stronger correlation, suggesting a potential paternal genetic effect on myopia susceptibility.

However, when examining the factors related to myopia progression over the 2-year period, the change in axial length showed a significant correlation with time spent on after-school homework and learning, but not with parental myopia. This finding highlights the importance of environmental factors, such as increased near work activities, in the progression of myopia, potentially overshadowing the genetic influence. Furthermore, the change in emmetropic power over the two-year period was significantly associated with both paternal myopia and time spent on after-school homework and learning. This indicates that while environmental factors are crucial, paternal myopia also plays a significant role in the progression of myopia. It is hypothesized that paternal myopia may influence the increase in corneal curvature rather than axial length, contributing to the myopic shift observed in emmetropic power. These findings align with previous research indicating that both genetic predispositions and near work activities are significant contributors to myopia development and progression. The results of this study provide further evidence for the complex interplay between genetic and environmental factors in the etiology of myopia, highlighting the need for a multifaceted approach to myopia management that addresses both inherited susceptibility and modifiable lifestyle factors.

The study also revealed that the mean axial length increased by 0.43 mm, and the mean emmetropic power showed a myopic shift of 1.2 D over the two-year period, underscoring the importance of monitoring axial length as a major indicator of myopia progression in children. The positive correlation between axial length and age observed in this study is consistent with the natural growth patterns of the eye. Interestingly, the study found that TV watching time, PC use time, and smartphone use time did not show significant correlations with axial length or emmetropic power, suggesting that while screen time is often considered a risk factor for myopia, its impact may be less significant compared to other factors such as genetic predisposition and near work activities.

The protective effect of outdoor activities against myopia progression has been well-documented, and this study supports this notion. The average time spent on outdoor activities increased from 1.96 hours to 2.33 hours over the two-year period. Exposure to natural light during outdoor activities is believed to stimulate the release of dopamine in the retina, which inhibits axial elongation of the eye, potentially explaining the observed protective effect of outdoor activities on myopia progression. Despite the substantial increase in the proportion of participants using smartphones for 4 hours or more, from 0.2% at baseline to 10.6% at the two-year follow-up, smartphone use time did not show significant correlations with axial length or emmetropic power. This suggests that while increased smartphone use is a notable trend, its direct impact on myopia progression may be less significant compared to other factors such as genetic predisposition and near work activities.

Recent studies have further emphasized the importance of outdoor activities in preventing myopia. For instance, He et al. (2015) found that children who spent more time outdoors had a significantly lower risk of developing myopia,[11] while Wu et al. (2013) demonstrated that increased outdoor time was associated with a reduced rate of myopia progression in Chinese children.[12] These findings support the notion that outdoor activities play a critical role in myopia prevention and should be a key component of public health strategies. Moreover, the role of near work and screen time in myopia progression has been extensively studied. A meta-analysis by Huang et al. (2016) concluded that prolonged near work is a significant risk factor for myopia, highlighting the need for interventions that limit screen time and encourage regular breaks during near work activities.[13] These insights reinforce the importance of balanced lifestyle interventions in managing myopia risk.

Limitations and Implications

This study has several limitations that should be considered when interpreting the results. First, the lack of gender data may limit the analysis of potential gender differences in myopia progression. Second, the reliance on self-reported lifestyle factors can introduce recall bias and inaccuracies, affecting the reliability of the findings. Third, the study was conducted in a specific geographical and cultural context, and caution should be exercised when generalizing these findings to other populations. Lastly, while cycloplegic refraction is considered the gold standard for measuring refractive error, it can cause discomfort due to pupil dilation. To avoid this, the study employed a non-invasive approach using a non-contact optical biometer to measure ocular biometry and calculate emmetropic IOL power as an indirect method. Future studies should incorporate objective measures, diverse populations, and control groups to strengthen the validity of the findings and better understand the causal relationships between lifestyle factors and myopia progression.

The findings of this study have important implications for public health strategies aimed at addressing the growing burden of myopia. The results suggest that promoting outdoor activities, managing near work and screen time, and considering genetic predispositions are crucial steps in mitigating myopia risk. These findings can inform the development of comprehensive public health initiatives that target modifiable risk factors and provide guidance for parents and educators to support healthy visual development in children. Furthermore, the study highlights the need for collaboration between schools and parents to create environments that support balanced lifestyles. Policymakers should consider these findings when developing policies to manage myopia, as integrating myopia prevention and control measures into public health policies can reduce the long-term economic burden associated with myopia-related complications. The study also emphasizes the need for further research to explore the long-term impact of lifestyle factors and genetic predispositions on myopia progression, including larger, longitudinal studies with diverse populations and the potential of machine learning models to predict myopia progression. Finally, increasing awareness among parents and educators about the implications of myopia and the importance of early intervention is essential.

Conclusion

In conclusion, this prospective cohort study provides valuable insights into the complex interplay of genetic and environmental factors in the development and progression of myopia among elementary school children in Jeju Island, South Korea. The key findings suggest that while parental myopia plays a role in the development of myopia, environmental factors such as extensive after-school learning may have a more significant impact on myopia progression. The change in axial length and emmetropic power over the 2-year period showed significant correlations with time spent on after-school homework and learning, highlighting the importance of environmental factors in myopia progression. Despite the limitations, these findings have important implications for public health, education, policy development, and future research, emphasizing the need for balanced lifestyles, outdoor activities, and management of near work and screen time to prevent and control myopia in school-aged children. Through attentive implementation of evidence-based strategies and further exploration of innovative technology such as the machine learning model, future generations can be alleviated of this burden of myopia.

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