

# Exercise Therapy in the Prevention and Control of Myopia in Adolescents

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## Abstract:

With the increase in the national economic level, the proportion of myopia among adolescents in China has been rising rapidly and is now a serious public health problem. In light of the above serious circumstances, traditional treatments such as spectacle correction, orthokeratology (OK lenses) and pharmacological therapy have been applied; however, they are mostly passive corrections or carry risks of side effects and rebound. Exercise therapy is a type of "active behaviour intervention" that, owing to its non-invasive and sustainable features in line with the body's physiological requirements, has gradually been added to the myopia prevention and control system. Based on the above, the mechanisms of exercise therapy can be summarized in two parts. First is the secretion of dopamine, and second is the ciliary muscle spasm in the eye. Exercise therapy will also focus on these two aspects. Exercise therapy has some strengths, but it also has some deficiencies; currently, these problems include difficulty in quantifying light exposure, a lack of standardised exercise prescriptions, and low compliance due to academic pressure. In the future, research and applications will focus on developing particular exercise programs, exploring technology that combines phototherapy and exercise, using multi-omics analysis to identify the molecular foundation, and building an intelligent monitoring system. The purpose of these efforts is to transform exercise therapy from general recommendations into a specific and highly effective medical strategy for preventing and controlling myopia, thus implementing the concept of "integration of sports and medicine" and promoting the achievement of the goals for "Healthy China 2030".

**Keywords:** Myopia exercise therapy; Retinal dopamine; Ciliary muscle accommodative spasm.

## 1. Introduction

With the increase in the overall economic level of China, cases of myopia among young people have been gradually rising. It is expected that by 2050, the proportion of myopia among Chinese adolescents aged 16-18 will reach 81.5%, and the number of people with myopia in China and around the world is projected to increase from 1.4 billion in 2000 to 4.8 billion by 2050 [1]. There are many causes of myopia, and some are environmental and others are hereditary.

At present, the main modes of myopia prevention and control in China are spectacle correction, orthokeratology (OK) lenses, low-concentration atropine and refractive surgery. However, these methods also have their own deficiencies: spectacles correct vision but do not slow down axial elongation; although OK lenses and low-concentration atropine can reduce the progression of myopia to a certain extent, they are associated with risks such as corneal infection, adverse drug reactions, and rebound effects after discontinuation; refractive surgery is only suitable for adults with stable refraction and cannot prevent fundus complications in high myopia. It can be seen that the above interventions are mainly "passive corrections" or "pharmacological/device-based treatments", and it is difficult to achieve long-term, non-invasive, and sustainable myopia prevention at the behavioral root.

Exercise therapy is a type of active behaviour intervention for the body. Natural-Light Stimulation of outdoor exercise increases dopamine release in the retina, thickens the choroid, and suppresses excessive axial elongation. Exercise can also relax the ciliary muscle to improve accommodation of the eye, lower intraocular pressure, and is free from drug toxicity or surgery. Based on this scientific evidence, the Outline of the "Healthy China 2030" Plan explicitly calls for "strengthening the integration of sports and medicine, as well as non-medical health interventions" [2]. Similarly, the Comprehensive Implementation Plan for the Prevention and Control of Myopia in Children and Adolescents requires that "adolescents should engage in no less than two hours of outdoor activities daily", and schools and parents need to guide children and adolescents to participate in outdoor sports to ensure daily exposure to natural light. Therefore, the above policies require the application of exercise therapy for myopia prevention and control. However, systematic reviews on the application of exercise therapy for preventing adolescent myopia are still lacking, and especially comprehensive syntheses of the past three years have not been published. However, systematic reviews on the application of exercise therapy for preventing adolescent myopia are still lacking, and especially comprehensive syntheses of the past three years

have not been published. Accordingly, this study systematically summarizes advances in exercise therapy for adolescent myopia. Based on the mechanisms of retinal dopamine modulation and alleviation of ciliary accommodative spasm, we investigate the combined intervention of ball games and aerobic exercise, aiming to supply theoretical support and practical guidance for adolescent myopia prevention and control.

## 2. Mechanisms of Exercise Therapy in Myopia Prevention and Control

Exercise therapy is not only about exercise but can also regulate the development of myopia in young people in other ways. The two types of its operation are shown below:

### 2.1 Retinal Dopamine (DA)

Dopamine directly suppresses the D2-receptor-ERK pathway to inhibit the extension of the nucleus and is thus one of the reasons why myopia progression is delayed. The way this path works is as light activation: Outdoor natural light and blue light stimulate retinal dopaminergic cells (DACs) to release dopamine [3]. Dopamine binds to the D2 receptors on the DACs or in the posterior scleral fibroblasts, activates the Gai protein pathway, inhibits adenylyl cyclase (AC), and thus reduces the concentration of cAMP. At this time, the low cAMP level inactivates protein kinase A (PKA) and thus fails to inhibit Raf kinase. Simultaneously, ERK phosphorylation may be directly inhibited and inactivated by a beta-arrestin-dependent mechanism. The inactivation of the ERK pathway results in a lower level of expression for matrix metalloproteinase-2 (MMP-2) and thus inhibits the breakdown of the scleral extracellular matrix and delays axial elongation.

Research has shown that the expression of D2 receptors (DRD2) is relatively high in the posterior scleral fibroblasts compared to the anterior ones, and D2 receptor activity can counteract the inhibitory effects of dopamine on scleral remodeling. Therefore, D2 receptors are likely involved in regulating myopia, and abnormal activity may lead to excessive axial elongation.

Dopamine regulates the metabolism and suppresses excessive axial elongation of the sclera by inhibiting the expression of proteases, such as MMP-2, that degrade the matrix; thus, it inhibits the breakdown of scleral collagen fibres. MMP-2 is a type of matrix metalloproteinase that directly degrades the extracellular matrix of the sclera to promote the lengthening of the axis. Second, it increases the expression of genes for collagen synthesis to promote the formation and strengthening of the sclera. Thirdly, it

increases the blood supply and thickness of the choroid to improve oxygenation in the sclera, thus reducing the expression of hypoxia-inducible factor 1 alpha (HIF-1 $\alpha$ ), which is a factor that promotes the progression of myopia. Finally, it increases the density and elasticity of the scleral fibre layer to strengthen the toughness of the scleral fibres and prevent abnormal axial elongation.

There is a periodic fluctuation in dopamine release in the retina related to the initiation of myopia.

It has a low secretion in the daytime and a high secretion at night. The two main reasons are as follows. First, artificial light interference: Exposure to artificial light at night disrupts the circadian rhythm, inhibits melatonin secretion, reduces dopamine release, and thus increases the risk of myopia. Second, direct genetic regulation of the biological clock: DACs express core clock genes to form an autonomous oscillator, thus achieving a circadian rhythm (high during the day and low at night) in dopamine release that is independent of the central clock [4].

Research on how directly acting receptors in the retina modulate axial elongation via dopamine pathways has not yet been conducted in the field of outdoor exercise. Increase the amount and wavelength of light that stimulates dopamine release at the core level. The Light Intensity Requirement for the activation of DACs and the maintenance of dopamine secretion is over 1000-2000 lux. The total time of exposure should be 4 hours per day of outdoor exercise. Research has shown that children who are out of doors for more than two hours each day are 60 per cent less likely to be nearsighted than those who spend most of their time indoors, and regular exercise outdoors can reduce the progression of myopia in nearsighted children by 50-75 per cent. In addition, for every extra hour of outdoor exercise per week, the risk of myopia will be reduced by 2%. At this time, one can accumulate the above segments (e.g., 40 minutes in the morning + 30 minutes at noon + 50 minutes in the afternoon), but a single session should ideally be no less than 20 minutes long to ensure that dopamine reaches an effective concentration. Finally, consider the environment and conditions for use; natural light is needed, and outdoor exercises on a cloudy day or in winter are not suitable. As glass blocks most ultraviolet rays and some of the blue light spectrum that is beneficial for myopia prevention, indoor lighting near windows is only 10%–30% as intense as outdoor light and thus fails to effectively stimulate dopamine secretion. Therefore, Glass obstructions should be avoided.

## 2.2 Relief of Ciliary Muscle Accommodative Spasm

The Ciliary Muscle needs to change the focus of the eye

at different times. It is between the iris and the choroid, arranged in a ring, and consists of smooth muscle fibres. Given its location, a small change in the shape of the lens can be achieved by contraction or expansion; thus, the area of a person's clear-vision zone is modified. The components of the tissue include longitudinal, radial and circular muscle fibres in the ciliary muscle. The above complicated structure can be used to control multi-directionally varied tension during accommodation and thus adjust the curvature of the lens precisely. The Ciliary muscle is next to the sclera and choroid and closely related to these structures. These structures provide support for the ciliary muscle and are also involved in regulating the circulation of aqueous humour. Studies have found that the structure and position of the ciliary muscle in emmetropic and myopic eyes differ; thus, these changes may be related to the development of myopia through modifications in the accommodative function of the eye.

The first purpose of the ciliary muscle in the visual system is to alter the shape of the lens for near and far focus, thus improving image clarity at different distances. When one is looking at an object, the ciliary muscle will contract and the zonular fibres will be relaxed. Therefore, the crystalline lens is elastic and will increase in size; thus, it can enhance the refractive power and focus light more precisely at the retina to produce a clear image. At the same time, when looking at distant objects, the ciliary muscle relaxes, the zonular fibres become tight, and the lens returns to a flatter position with a lower refractive power for far-sightedness. The position of the ciliary muscle and the curved crystalline lens are working together to change the curvature of the lens, and this movement is also regulated by the parasympathetic nervous system. However, prolonged near work or over-reliance on accommodation may cause fatigue of the ciliary muscle and accommodative spasm, thus reducing the normal focusing ability of the lens. It may be that this is a primary reason for the development and progression of myopia.

The outdoor environment is relatively far away, so the ciliary muscle does not need to work continuously to focus on near objects. Ciliary muscles need to contract continuously near the working distance to maintain a normal state for the lens, and prolonged contraction may lead to accommodative spasm [5]. At the same time, a large field of view and distant objects in the outdoor scene can extend the ciliary muscle effectively for full recovery of the ciliary muscle after prolonged contraction. Distance viewing reduces the accommodative demand on the ciliary muscle by decreasing changes in lens curvature; thus, the muscle is less strained and symptoms of visual fatigue may be improved [6]. Distant viewing away from the city is often done in nature; therefore, changing visual stimuli may

expand the accommodation range of the ciliary muscle and help restore function. Thus, it is thought that distance viewing during outdoor exercise is one of the reasons for reduced accommodative spasm.

At the same time, dynamic visual stimuli in the open-air environment can also be employed to expand the accommodation range of the ciliary muscle. Outdoors are changing places, with many moving things and variations in light and shadow; they are not fixed indoor scenes. The modified visual information will continue to activate the focusing function of the ciliary muscle, shifting the point of accommodation quickly to increase both the resolution and sensitivity of focusing. For example, when running or cycling, there are rapid changes in the visual scene, so the ciliary muscle needs to change focus frequently to adjust to different. For example, during running or cycling, there are often rapid changes in the visual environment, so the ciliary muscle need to adjust frequently to focus on different objects. As shown in the dynamic exercise mode above, increasing the contraction-relaxation capacity of the ciliary muscle can reduce the risk of accommodative spasm. Ball sports are also outdoor exercises that provide rich dynamic visual stimuli; thus, rapid tracking of moving objects by the ciliary muscle and extraocular muscles can enhance the accommodative flexibility of the ciliary muscle through cooperation among these muscles. Research has shown that children and adolescents who regularly engage in such outdoor sports have significantly better ciliary muscle accommodative function than those who do not participate in outdoor exercise, and thus support the application of outdoor exercise for myopia prevention and control [7].

### 3. Application of Exercise Therapy in Myopia Prevention and Control

#### 3.1 Related Studies

Several comparisons were conducted in the study "The relationship between physical exercise, myopia prevention and physical development in children: a one-year longitudinal intervention study" to examine the impact of exercise intervention on myopia. After one year of intervention, the changes in ocular biometric parameters of the normal vision control group and the normal vision intervention group were compared; the normal vision intervention group showed a mean reduction in spherical equivalent refraction (SER) of 0.08 D, which was significantly lower than the 0.50 D reduction in the normal vision control group ( $P < 0.01$ ). The mean increase in axial length (AL) in the normal-vision intervention group was

0.30 mm; the change in corneal curvature radius (CR) was  $(0.00 \pm 0.33)$  mm; the rise of the AL/CR ratio was 0.04; and the extension of anterior chamber depth (ACD) was  $(0.14 \pm 0.13)$  mm. All of these values were lower than the changes in the normal vision control group, but they did not reach statistical significance. Moreover, in terms of the comparison of the incidence of new-onset myopia in the two groups, 18 students in the normal vision control group developed myopia during the one-year intervention and follow-up period, with an incidence rate of 48.6%. On the other hand, 13 students in the normal vision intervention group developed myopia, and the incidence rate was 35.1%; this was significantly lower than that in the control group ( $P < 0.05$ ).

After one year, the intra-group changes in ocular biometric parameters of the myopia control group and the myopia intervention group were compared, and the SER in the myopia control group was  $(-1.94 \pm 1.20)$  D; it was significantly lower than the baseline value of  $(-1.23 \pm 0.89)$  D ( $P < 0.01$ ). The AL was  $(24.30 \pm 0.69)$  mm and significantly larger than the baseline value of  $(23.81 \pm 0.69)$  mm ( $P < 0.01$ ). The AL/CR ratio was  $3.02 \pm 0.14$ , which was significantly higher than the baseline value of  $2.96 \pm 0.14$  ( $P < 0.05$ ), and the ACD was  $(3.28 \pm 0.26)$  mm; this was also significantly larger than the baseline value of  $(3.19 \pm 0.29)$  mm ( $P < 0.05$ ). In addition, CR did not change significantly before and after the intervention ( $P > 0.05$ ). Neither SER nor CR changed significantly in the myopia intervention group after one year ( $P > 0.05$ ). However, the AL was  $(24.43 \pm 0.69)$  mm, which was significantly higher than the baseline value of  $(24.02 \pm 0.69)$  mm ( $P < 0.01$ ); the AL/CR ratio was  $3.28 \pm 0.14$  and significantly higher than the baseline value of  $3.21 \pm 0.14$  ( $P < 0.05$ ); and the ACD was  $(3.28 \pm 0.26)$  mm, which was also significantly higher than the baseline value of  $(3.21 \pm 0.29)$  mm ( $P < 0.05$ ).

Finally, when comparing the inter-group changes in ocular biometric parameters after the one-year intervention of the myopia control group and the myopia intervention group, the SER in the myopia intervention group decreased by  $(0.22 \pm 0.97)$  D, which was significantly lower than the decrease of  $(0.70 \pm 0.66)$  D observed in the myopia control group ( $P < 0.05$ ). The AL in the myopia intervention group increased by  $(0.41 \pm 0.22)$  mm and the ACD deepened by  $(0.07 \pm 0.23)$  mm; both were lower than the changes in the myopia control group but did not reach statistical significance. The reduction in CR for the myopia intervention group was  $(0.06 \pm 0.41)$  mm, and the increase in AL/CR ratio was  $0.07 \pm 0.16$ ; neither reached statistical significance and were smaller than the changes in the myopia control group. Therefore, based on the above results, exercise can improve the function of accommodation in

the ciliary muscle and enhance blood circulation to the eye; it may help prevent new-onset myopia and reduce the speed of progression in existing myopia.

### 3.2 Exercise Selection

Aerobic exercise and ball sports are the first choices for the type of exercise therapy. Among aerobic exercises, running is often selected because changes in the visual environment during running can activate the function of ciliary muscles to some extent. Running is continuous motion; thus, the displayed pictures will change regularly. Change of light can increase the radius of accommodation and reduce spasm of the ciliary muscle after extended near-point work. According to the research, modifications in the visual environment continuously trigger the contraction-relaxation mechanism of ciliary muscles, keep the muscle in an active metabolic state, and improve accommodation [8]. Running also requires keeping one's eyes on an object at different distances continuously [9]. The two modes of focus, far and near, are not used simultaneously, so the ciliary muscle is less likely to be in a state of prolonged contraction. Empirical studies have also shown that people who exercise regularly over a long period of time have a relatively low risk of developing myopia and show greater stability in ciliary muscle accommodative function; thus, running may also be effective in preventing and managing myopia.

Among ball sports, badminton is relatively fast-paced and high-intensity; therefore, many studies have shown that it can effectively exercise the accommodative flexibility of the ciliary muscle. Players need to track the high-speed shuttlecock continuously during a badminton match, and these rapidly changing visual targets place a very high demand on the accommodative function of the ciliary muscle. Visual tracking of badminton can strengthen the contraction-relaxation function and improve the accommodative flexibility of the ciliary muscle, and at the same time, it can reduce accommodative spasm. Shuttlecocks in badminton are also generally travelling at speeds of tens of metres per second. Rapid visual changes can make the cilia of the ciliary muscle work repeatedly in a short period and increase their range of movement. Rapid-movement visual-tracking tasks in badminton can also trigger the release of retinal dopamine and thus improve the function of ciliary muscles at a neurophysiological level. Dopamine is a neurotransmitter that can also reduce the length of the axis and relieve accommodative spasm to a certain extent. Based on the previous research, high-intensity visual stimulation in badminton has increased dopamine levels in the retina and extended the benefits of ciliary muscle accommodation. In addition, the multiple

directions and turns of running in badminton can increase blood flow to the eyes, provide more oxygen and nutrients for the ciliary muscle, and thus improve the metabolism of the ciliary muscle to enhance accommodation [10,11]. Together, these mechanisms work to make badminton an excellent exercise for the eyes outside of the classroom that reduces accommodative spasm of the ciliary muscle and can prevent myopia.

### 4. Conclusion

Research and evidence in the field of exercise therapy have found some protective effects; further practical promotion and scientific research are needed.

The first is that people don't know how the light affects it. Most of the current research focuses on the general index of "outdoor time" and does not specify how light exposure is calculated. Fluctuations in light intensity at a specific time, differences in the spectral distribution (such as the ratio of blue light to ultraviolet light), and whether the light passes through glass are all difficult to account for in real-world measurements; thus, the dose-response curve for different people will vary. At the same time, there is no standardised exercise intensity or type. No research has identified a single type of exercise as superior to others yet; although ball sports and running have shown certain benefits, their visual stimuli (such as tracking high-speed objects versus observing fixed distant targets) and physiological loads (aerobic metabolic level) are quite different. At present, there are no unified norms for exercise prescriptions (e.g., specific combinations of intensity, frequency and duration). Other Reasons for Changes in the Data. Based on observations, people who are out in the open more frequently generally belong to higher socio-economic groups, live closer to their workplaces, and may possess genetic advantages. It is difficult to know whether "exercise" itself is responsible for the improvement; perhaps some of the observed benefits result from a decrease in near-work behaviour when outdoors. Finally, there are problems of compliance and environmental restrictions. Given the heavy academic pressure in recent times, many teenagers have been unable to exercise outdoors for the recommended two hours each day. In addition, there are other reasons why natural light may not be readily available, such as a short day in winter or a high-latitude or rainy area.

Myopia in young people is now a serious problem for public health in China. In light of the increasing severity of the epidemic, the traditional correction methods of spectacle correction, orthokeratology (OK) lenses and pharmacological interventions are either passive corrections or have risks of side effects and rebound. As an "ac-

tive behaviour modification technique", exercise therapy has also been added to the myopia prevention and control system due to its non-invasive and long-term nature, which meets the actual needs of the people concerned.

Based on the above analysis, the mechanism of action for myopia prevention and control by exercise therapy mainly includes two types of effects:

Firstly, there is an activation of the retinal dopamine (DA) pathway. High-intensity natural light (>1000-2000 lux) outdoors during exercise is required to stimulate the release of retinal dopamine. Dopamine suppresses the expression of matrix metalloproteinase-2 (MMP-2) through the D2 receptor-ERK pathway, thus inhibiting the degradation of the scleral extracellular matrix, strengthening the sclera, and directly inhibiting excessive axial elongation. Increased light exposure may also promote the expansion of choroidal blood vessels and thickening of the choroid to reduce scleral hypoxia.

Secondly, reduce the accommodation spasm of the ciliary muscle. Numerous studies have shown that the tension and spasm of the ciliary muscle caused by prolonged near work are sufficient to induce myopia. Outdoor exercises, such as ball sports (e.g., badminton) and running, are relatively far away and have dynamic visual changes. This visual environment needs the ciliary muscle to change frequently between "contraction" and "relaxation", so there will be no prolonged tension and effective relief of accommodative spasm to restore the accommodative flexibility of the crystalline lens.

In short, after accumulating no less than two hours of daily outdoor exercise, there are biological reasons for restricting the extension of the spine at a molecular level and improvements in the function of accommodation by relaxing physical muscles and exercising the eyes. This is a good way to achieve the goal of integrating sports and medicine for the primary prevention of myopia in adolescents.

Therefore, in the future, research and practice will focus on the following directions to further optimize the application of exercise therapy for myopia prevention and control:

Firstly, design the particular exercise plan that will be employed. Future research can aim to build an evidence-based "myopia prevention exercise prescription database". Using randomised controlled trials (RCTs), specific differences in the effects of various exercise types (e.g., badminton, soccer, jogging) on accommodative amplitude, choroidal thickness and dopamine secretion should be explored to offer personalised exercise recommendations for adolescents with different types of myopia (e.g., accommodative lag type, rapid axial elongation type).

The second is the integrated technology of phototherapy and exercise. In Areas or at times when there is insufficient light, models that integrate high-intensity light equipment with natural-spectrum simulation can be used for indoor physical education classes. In addition, VR/AR training systems that can simulate dynamic visual stimuli in outdoor environments are also available to help people exercise without going outside due to circumstances such as "no outdoor access".

The third is the comprehensive study of the mechanism through multiple '-omics'. In addition to the dopamine pathway, metabolomics and transcriptomics technology can also be applied to explore the regulatory mechanisms of exercise on local ocular signalling molecules (such as IGF-1 and retinoic acid in the aqueous humour and sclera), and thus reveal the full biological chain of how "systemic exercise" leads to "local ocular protection".

The fourth way is intelligent supervision and feedback. Wearable devices (such as light sensors and eye trackers) can be used to monitor adolescents' outdoor light exposure and ocular accommodative status in real time to build a digital myopia risk early warning system. Big Data analysis will be applied to customise intervention strategies and achieve the goal of digitalisation in myopia prevention and control.

Finally, there is the problem of policy and environment coordination optimisation. It is proposed that the education office add more hours to physical education classes under the "double reduction" policy. At the same time, urban planning should expand the area of green open space in the community to provide adolescents with more outdoor spaces and unobstructed views for sunlight. Through the above efforts, exercise therapy is expected to move away from general health advice and become a specific, high-efficiency, and measurable medical intervention for the prevention and control of myopia, providing strong support for achieving the strategic goals of "Healthy China 2030".

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