Prevention of Myopia Onset

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Key Points
- Time spent outdoors is well recognized as a factor preventing the development of myopia onset, and measures including adding an outdoor class, locking classroom doors during class recess, or glassed roof and walls incorporated in a classroom have been developed. But promotion to increase time spent outdoors as a school-based intervention program remains challenging especially in East Asia.
- Near work activity has been suggested as a risk factor for myopia although the evidence is not entirely consistent. The total duration of near work activity may not be as important as the type of near work activity. Core techniques to implementing interventions of near work activities include effective measures of near work-related parameters, real-time data analyses, and alert systems.

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- School children growing up in myopigenic environments are likely to benefit from optical interventions designed to induce myopic defocus. The lens with multiple segments of defocus showed promising effect on slowing progression of myopia.
- The Chinese eye exercises of acupoints advocated in mainland China and Taiwan were designed to relieve ocular fatigue and reduce the development and progression of myopia. But clinical significance of its efficacy has not been established according to available data.
- Maximizing the utility of time outdoors is still the priority in the prevention of myopia onset. The role of screen time in myopia development is still ambiguous, the restriction may enable more time for children to go outdoors. Other approaches to prevent myopia onset still require further investigations, such as imposed myopic defocus, low-dose atropine, or some novel pharmacological agents for non-myopes.

7.1   Introduction

Over recent decades, the prevalence of myopia in school-aged children has been increasing significantly in East Asia. Up to 80% of junior high school students have myopia, of which 20% have high myopia in mainland China [1, 2], Hong Kong [3], Taiwan [4], South Korea [5], Japan [6], and Singapore [7]. Longitudinal data suggests that the incidence of myopia is around 10–20% per year among school-aged children [8–11]. If the onset of myopia can be delayed, the prevalence of myopia as well as high myopia in school-aged children will likely reduce. This chapter focuses on the clinical strategy to prevent or delay the onset of myopia among school-aged children, summarizing the interventions currently available, and takes a glance at future perspectives.

7.2   Onset of Myopia

The vast majority of literature suggests that most cases of myopia develop during the school-going age in children. The prevalence of myopia among preschool children is relatively low [12–15]; furthermore, a longitudinal study in Shunyi Beijing demonstrates that the annual incidence of myopia among 5-year-old children is below 5% [16]. After the age of 6 years, the prevalence of myopia starts to rise [6, 16–19]. The highest annual incidence of myopia is reported among school children from urban mainland China [18] and Taiwan [20], ranging from 20% to 30% through ages 7–14 years with earlier onset of myopia also being identified [6]. A study in Japan showed that while the prevalence of myopia has been increasing from 1984 to 1996, the prevalence among children aged 6 or younger has remained

unchanged. This suggests that the majority of increased myopia onset is secondary to increased educational intensity and develops when children reach school age (Fig. 7.1) [6].

A long-term longitudinal study has demonstrated that there is a steady shift in refraction toward myopia, before the actual onset of myopia. Rates of progression increase dramatically the year of onset and this has been suggested by spherical equivalent refraction and axial length (Fig. 7.2) [21]. After the first detection of
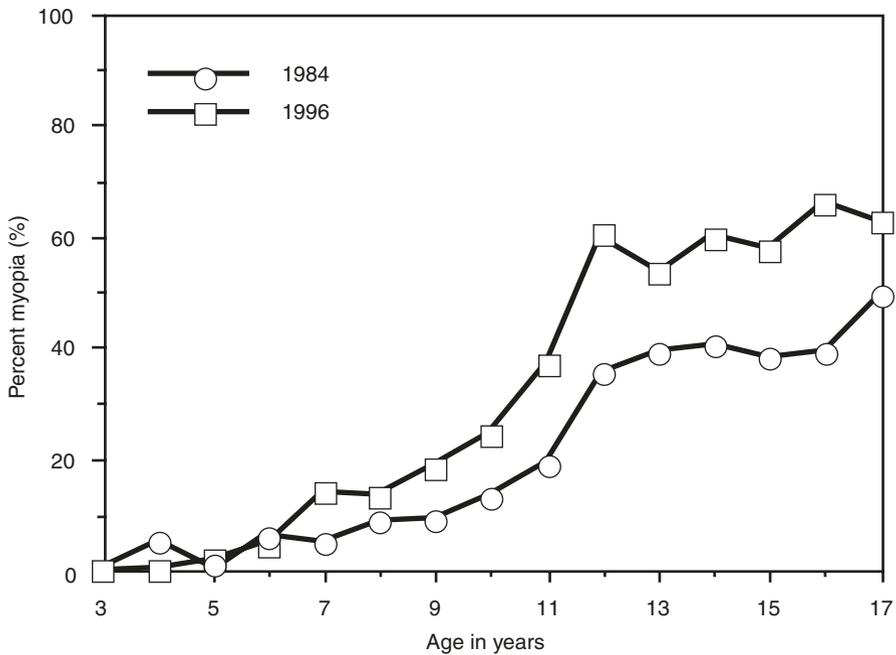
Fig. 7.1 Age-specific prevalence of myopia in Japan in 1984 and 1996. © Matsumura et al. [6]
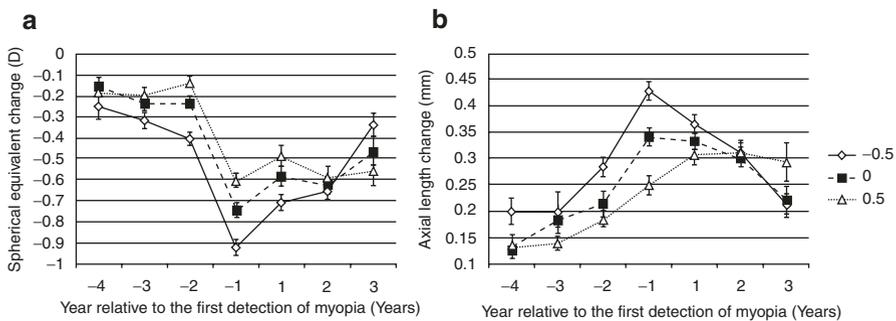
Fig. 7.2 Changes in spherical equivalent refractions (**a**) and axial lengths (**b**) before and after myopia onset. © Xiang et al. [21]

myopia, this acceleration is reduced (Fig. 7.2) [21, 22]. Myopic refractions tend to stabilize in late adolescent but can remain progressive until adulthood. The mean age at myopia stabilization is 15.6 years but this can vary among children of different ethnicities [23].

Several factors have been found to be associated with the development of incident myopia in school. Asian ethnicity [19, 24], parental history of myopia [25, 26], reduced time outdoors [26], and level of near work activity [27, 28] are risk factors for incident myopia, although the evidence can be seen as controversial in some instances. Some studies have also suggested that non-myopic children with less hyperopic refractions and greater axial length/corneal radius of curvature ratios are more predisposed to develop myopia [18, 19]. The impact of gender to the development of myopia varies among populations. In Chinese school children, females have a greater chance of progressing to myopia [18]; while in multiethnic populations, gender seems to be less impactful [19, 24, 27].

Attempts have been made to establish tools to identify children at risk of developing myopia or high myopia. Among numerous associated factors, spherical equivalent refraction is the most promising predictor. By using a single measurement of refraction alone, future myopia onset of non-myopic children can be accurately predicted [29]. Moreover, children at risk of developing high myopia in adulthood can also be identified, with reasonably good sensitivity and specificity, when using an age-specific 5th percentile curve of refraction of the population (Fig. 7.3) as a cutoff [30]. Other promising tools for the prediction of future high myopia include the age of myopia onset [31] and age-specific annual refraction progression of children with myopia (Fig. 7.4) [32]. Information on age of myopia onset alone can predict high myopia with 85% accuracy using a receiver operating curve (ROC) [31].
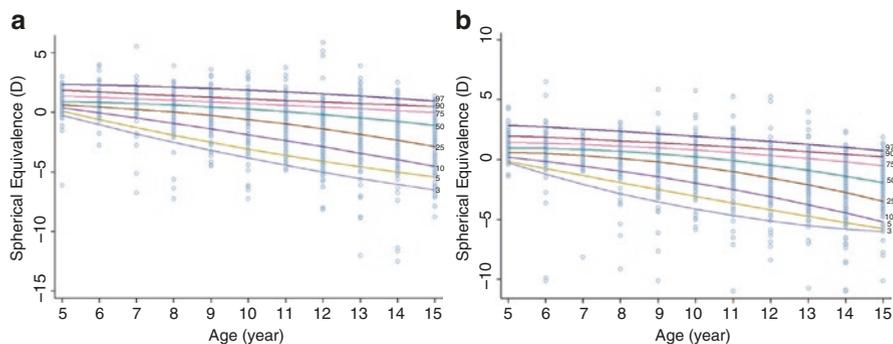

Fig. 7.3 Percentile curves of refractions for urban Chinese boys (**a**) and girls (**b**). © Chen et al. [30]

The chart shows bars with the following values:

Observed progression (black bars):
- Age 6: −1.06
- Age 7: −0.94
- Age 8: −0.77
- Age 9: −0.64
- Age 10: −0.63
- Age 11: −0.59
- Age 12: −0.54
- Age 13: −0.49
- Age 14: −0.36
- Age 15: −0.28

Estimated progression (hatched bars):
- Age 6: −1.08
- Age 7: −0.90
- Age 8: −0.78
- Age 9: −0.70
- Age 10: −0.65
- Age 11: −0.61
- Age 12: −0.58
- Age 13: −0.53
- Age 14: −0.46
- Age 15: −0.36

$y = 0.0022x^3 - 0.0403x^2 + 0.2859x - 1.3244$
$R^2 = 0.9884$

■ Observed progression ⁄⁄ Estimated progression

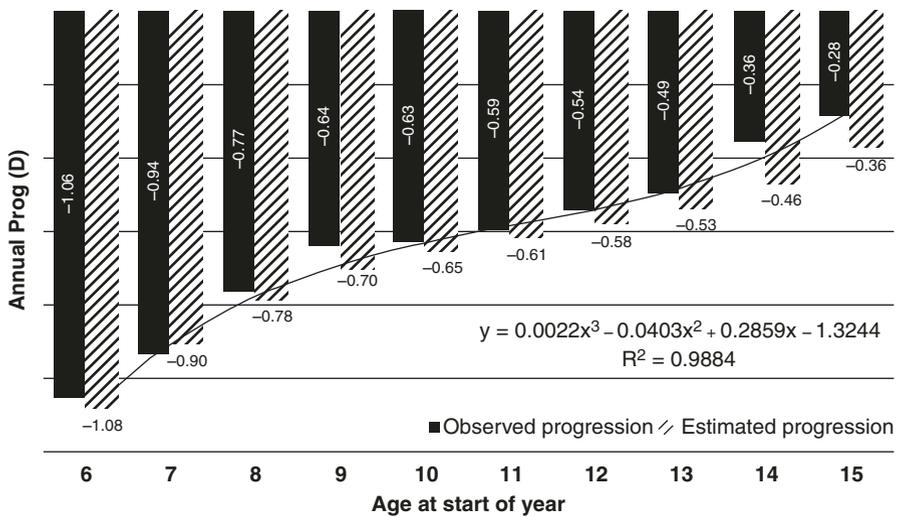Annual Prog (D) — Age at start of year

Fig. 7.4 Age-specific annual progression of refraction in children with myopia. © Sankaridurg et al. [32]

7.3 Increased Time Outdoors as an Intervention

Time spent outdoors is well recognized as a factor preventing the development of myopia onset. Evidence of this was first presented in a three-year follow-up study of myopia in school children, showing that those who spent more time outdoors were less likely to progress [33]. Consistent results were reported in various studies, such as the Sydney Myopia Study, Orinda study as well as the Singapore Cohort Study of Risk Factors for Myopia [34–36]. This led to the commencement of several clinical trials, which confirmed the protective effect against myopia and indicated a dose-dependent effect, among them is the randomized clinical trial in Guangzhou which reported that an additional 40 min of outdoor activity can reduce the incidence of myopia by 23%. Additionally, the trial in Taiwan suggested that an extra 80 min may further reduce incidence by 50% [10, 37].

The mechanism of increased outdoor time as an intervention is not completely clear. Spending time outdoors itself, instead of physical activities outdoors, has been suggested to be the major protective factor [38]. Results from animal experiments indicated that protection due to bright light may be mediated by dopamine [39]. Some believe that ultraviolet light also plays an important role [40], with evidence suggesting that there is an association between vitamin D level and myopia [41–43], but data from a population-based cohort did not support this idea [44]. Alternatively, patterns of defocus on the retina by three-dimensional structures of the environment have also been proposed as a possible mechanism of protection from outdoor activities [45].

As an economically feasible intervention, getting children outside the classroom has been promoted in many public health programs such as Taiwan's "Daily 120." However, promotion to increase time spent outdoors as a school-based intervention program remains challenging. First, what is an effective amount of time outdoors? Population-based data suggest that 2–3 h a day would be beneficial [26, 35], however, this is difficult to achieve in some East Asian countries where the education system is very intensive. Some programs recommend adding an outdoor class into the curriculum, while others recommend prohibiting being inside during recess by locking classroom doors. Another group of researchers proposed a classroom design that incorporates a glassed roof and walls that enable maximize light intensity while students study indoors (Fig. 7.5) [46]. The protective effect of this bright classroom is now under investigation. Second, what is the appropriate location for outdoor activities? The ideal location appears to be in an area with bright light more than 10,000 lux, suggested by evidence from animal experiments [47, 48]. But the most recent results from Wu et al.'s study indicated that less bright light exposure, 1000-lux or 3000-lux for instance, is sufficient enough to generate a protective effect (Fig. 7.6) [49]. These findings seem to suggest that an environment such as the shade of a tree or building, the hallway, or playground could still work with an advantage to avoid sunburn or other side effects from UV exposure.

Another concern is how do we measure outdoor activities? Traditionally, questionnaires have been commonly used to measure time outdoors but are less accurate due to recall bias. Objective measures can provide more precise real-time data. Wearable detectors have been developed to record light intensity and time outdoors, and even track the patterns of outdoor activities, including HOBO light meters, Nike+ Fuel Band, and others. Other measures have been used to estimate exposure to natural light such as conjunctival ultraviolet autofluorescence and skin photodamage, but these are more appropriate when measuring the cumulative light dosage or UV exposure [50, 51].

If increased time spent outdoors can prevent or delay the onset of myopia, it would ultimately reduce the prevalence of myopia or even high myopia among

Fig. 7.5 Classroom constructed with glass in China. ©Zhou et al. [46]
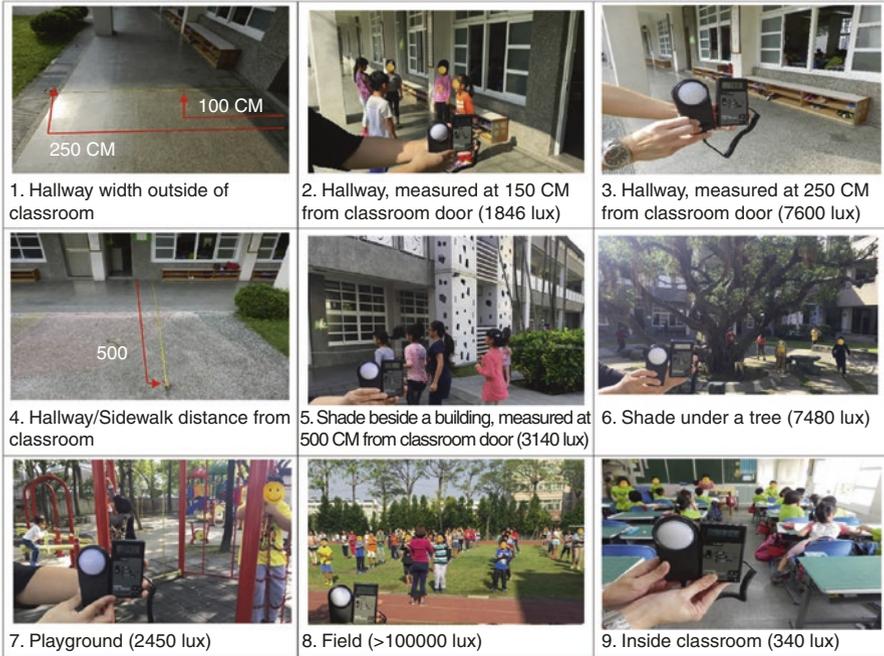
Fig. 7.6 Light intensity of different locations in the school. ©Wu et al. [49]

school-aged children. Documentation on the impact of time spent outdoors on the prevalence of myopia is of public health importance.

7.4   Reduced Near Work Intensity as an Intervention

Near work activity as a risk factor for myopia has been documented in some studies, although the evidence is not entirely consistent. A recent meta-analysis has reported a modest, but statistically significant, association between time spent performing near work and myopia (odds ratio, 1.14) [28].

It has been argued that the total duration of near work activity may not be as important as the type of near work activity. Studies have found that continuous reading of more than 30–45 min is associated with the presence of myopia and greater myopic refractive errors [52, 53]. Interestingly, after prolonged continuous reading, children are more likely to take up their preferred relaxed postures [54], such as close reading distance [53] and head tilt [52], both of which have been reported to be associated with the presence of myopia. Other factors that have been proposed to potentially contribute to the development of myopia include close nib-to-finger distance [52], downward angle of gaze [55, 56] and inadequate desk [52], or classroom lighting [56].

Efforts have been dedicated to developing novel devices to detect and correct inadequate near work behaviors. In mainland China, pens for myopia prevention has been invented. The pens are capable of detecting close reading distances (China Invention Patent, 200620010200.6) or nib-to-finger distances (China Invention Patent, 201020640746.6). Real-time retraction of the nib will occur when the eyes are too close to the reading materials or the nib-to-finger distance is inadequate, compelling children to adopt correct postures. The effect of the pens on preventing myopia onset is to be examined by future clinical trials.

Core techniques to implementing interventions of near work activities include effective measures of near work-related parameters, real-time data analyses, and alert systems. Wearable devices that possess these techniques have emerged in the last decade. A head-mounted instrument (Fig. 7.7) was built in Hong Kong for continuous logging of near work distance [57]. Measurements have proved to be accurate and repeatable over a range of distances and angles [57]. The Clouclip (Fig. 7.8) is another novel device developed in mainland China, primarily for the use of

Fig. 7.7 Front view (**a**) and side view (**b**) of the near work analyzer for logging near work distance and its alignment in a straight-ahead position (**c**) and reading position (**d**). © Leung et al. [57]

Fig. 7.8 Clouclip to monitor near work time. © Wen et al. [58]
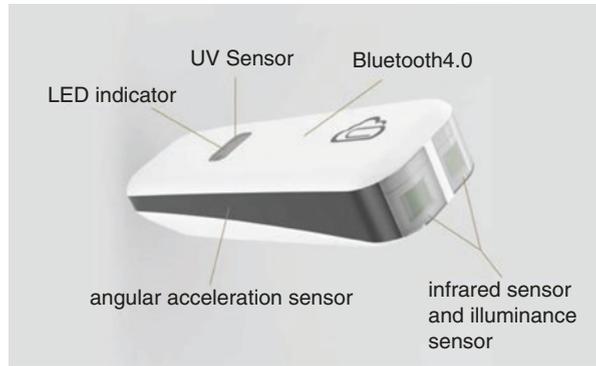
myopic children [58]. The device can measure reading distances and ambient illuminance, perform real-time data analyses, and feedback to children and parents (www.clouclip.com). This group of researchers used Clouclip to track reading distance and eye-level illuminance of children over a representative period of time [59]. Based on these data, they developed a summative index and found that a change in the index toward a more myopic behavior was significantly associated with increased myopic refractive errors in a preliminary longitudinal study [59]. The attempt to generate a simplified, summative index for risk estimation will help provide comprehensive information on near work-related behaviors and may help improve the efficacy of interventions.

7.5 Optical Interventions

The use of noninvasive optical interventions to prevent myopia is based on findings of the powerful STOP signals reported in numerous animal studies. By briefly exposing chickens to myopic defocus (the STOP signals), eye growth induced by presenting minus lenses can be slowed dramatically (Fig. 7.9) [60, 61]. It is therefore suggested that school children growing up in myopigenic environments are likely to benefit from routine optical interventions designed to induce myopic defocus [62]. The intervention regimen should combine variables including age, lens power, and duration of exposure to achieve an adequate effect on delaying the development of myopia [62].

While these optical interventions are an attractive idea, they have not been fully explored in human subjects—this will be elaborated further in Chap. 13 (Optical interventions for Prevention of Myopia Progression). A recent study has prescribed plus lenses to non-myopic children aged 5–8 years who are at risk of developing myopia [63]. The plus lenses imposed a 1.0 D myopic defocus and the children wore the correction the entire day. No cases of myopia onset have been observed in this group of children during the follow-up period (ranging from 3 to 9 years) [63]. The robustness of these study findings needs to be examined by future investigations.
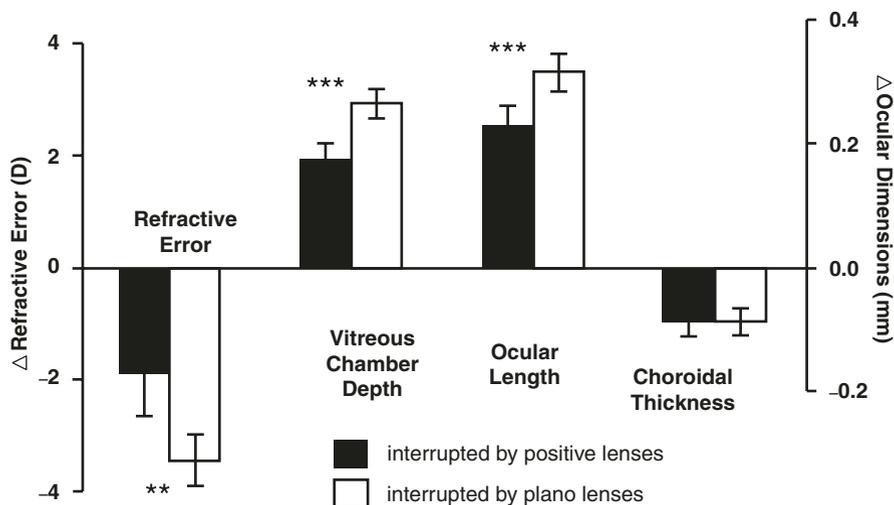
Fig. 7.9 Changes in refractions and ocular biometric parameters over 3 days of binocular negative lens wear interrupted by brief periods of positive lens wear on one eye and plano lens wear on the other eye. **$P < 0.01$; ***$P < 0.001$. © Zhu et al. [61]

The Defocus Incorporated Multiple Segments Lens (DIMS Lens) is a novel spectacle lens primarily designed for use in myopic children. The lens is composed of a central zone for optical correction of refractive error and an annular peripheral zone to induce myopic defocus. Interestingly, the lens peripheral zone contains numerous well-arranged small plus lenses, separated by small non-defocus areas. By using this design, myopic defocus is induced and visual quality is well reserved at the same time (presentation at the 16th International Myopia Conference [IMC]). In a pilot study conducted among school children, the DIMS lens slowed progression of myopia by 59% (presentation at the 16th IMC). The lens may also be promising for preventing myopia onset if adaptation can be successfully made for non-myopic children.

7.6 Eye Exercises of Acupoints

The eye exercises of acupoints are a set of bilateral acupoint self-massages designed to relieve ocular fatigue and reduce the development and progression of myopia. These eye exercises were introduced by the Chinese National Education Commission and have been advocated since the 1960s in mainland China and Taiwan. Children in primary and junior middle schools are required to perform the eye exercises twice a day. The 5-min exercises include: (1) knead Tianying (Ashi); (2) press and squeeze Jingming (BL1); (3) press and knead Sibai (ST2); and (4) press Taiyang (EX-HN5) and scrape Cuanzhu (BL2), Yuyao (EX-HN4), Sizhukong (TE23), Tongziliao (GB1), Chengqi (ST1) (Fig. 7.10).
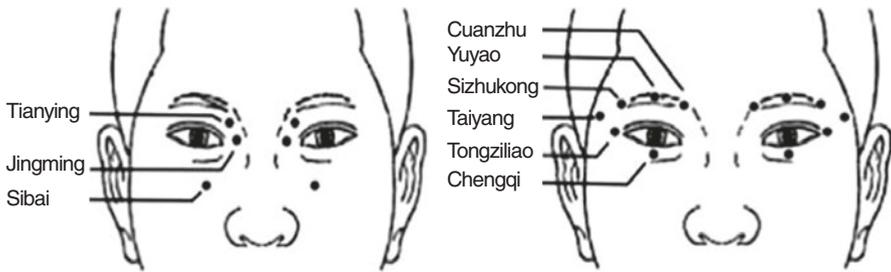
Fig. 7.10 Schematic diagram demonstrating the positions of acupoints used in Chinese eye exercises. © Lin et al. [67]

The efficacy of the Chinese eye exercises is believed to be from the theory of Traditional Chinese Medicine. By massaging the acupoints, Chi can be achieved and help relieve eye strain and recover ocular functions. Peak systolic velocity in the central retinal and ophthalmic arteries is observed after the eye exercises [64], which might provide some evidences to support this theory. Accommodative lag decreases significantly by 0.1 D after 5 min of performing the eye exercises [65].

Clinical significance has never been established in the published literature thus far. Cross-sectional studies have assessed the association between Chinese eye exercises and myopia with varied results [66–69]. The inconsistency can be explained by the different settings studied (rural vs. urban), failure to adjust for potential confounders (including parental myopia, time outdoors, and near work) and the lack of representative populations in some studies. In a recent study, the impact of Chinese eye exercises on the development of myopia has been examined using a longitudinal design [70]. No association between eye exercises and myopia onset has been found [70]. However, due to the limited sample size, low level of intervention time, and performance qualities of the exercises in the study, the actual impact is still not conclusive and needs to be justified by further studies.

7.7 Future Prospects

It has been estimated that without any effective controls or interventions the proportion of myopes in the population will reach up to 50% and 10% for high myopes by 2050 [71]. Approaches that have produced a reduction of at least 50% in incidence, such as time outdoors, have the potential to make a significant difference on the impending myopia epidemic. But the level of impact of the full utility of available interventions needs to be evaluated by further studies.

Another critical issue is how to implement both education intensity and outdoor time interventions in East Asia. There needs to be a balance between educational achievement and interventions delivered, which don't exacerbate the prevalence of myopia in East Asia. This balance can be seen in Australia [72], with some of the highest educational ranks in the world (PISA, https://www.oecd.org/pisa/data/) but

Fig. 7.11 FitSight fitness tracker to record time outdoors. ©Verkicharla et al. [73]

Light sensor

Time

Time spent outdoors

also high levels of outdoor activity and light intensity. Preventing the onset of myopia is certainly challenging in the East Asian population and requires a collaborative effort among clinics, schools, parents, and the entire society.

Nonetheless, maximizing the utility of time outdoors is still the priority in the prevention of myopia onset. The implementation of outdoor activities in school programs and daily life necessitates further propagation and feedback from parents and children. Novel devices combined with the internet and even social networks are a potential direction. An example is FitSight, which was developed by Saw et al. (Fig. 7.11) and comprises of a smartwatch with a light sensor and smartphone app that records time outdoors and sends feedback to parents and children [73]. This kind of devices needs to be proven to be useful by undertaking field study and determining wearability. Additionally, the price of the device should be considered in the design.

Another behavior control method focuses on limiting the screen time on computers, tablets, and smart phones. Though the role of screen time in myopia development is still ambiguous, the restriction may enable more time for children to go outdoors. Applications to provide screen distance and time monitoring, alerts to rest eyes, blue light filters, and remote locking capability for parents are available in some countries (plano, https://www.plano.co/). The effect of this technology on myopia prevention remains to be seen.

Other approaches to prevent myopia onset still require further investigations, such as imposed myopic defocus, low-dose atropine, or some novel pharmacological agents for non-myopes. They may help to prevent myopia in those who are rapidly progressing or have high-risk genetic forms. Thus, a question is raised: how do we identify children that have an increased risk of becoming myopic or highly myopic? Risk estimation is therefore critical to achieve personalized treatment for

individuals. For children who are non-myopic but at an increased risk of developing high myopia in the future, additional outdoor activities and aggressive approaches should be introduced with frequent follow-up visits. Tools of myopia prediction have been developed as mentioned before, and we expect to see the outcomes of the integration of risk prediction and clinical practice in the near future.

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