· Review ·

The measurement of time spent outdoors in child myopia research: a systematic review

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Abstract

● The purpose of this article is to summarize the methods most commonly used to measure time spent outdoors and provide a comprehensive review of time and activity recording methods with the aim of encouraging the development of new methods. PubMed, Embase and the Cochrane Library were searched from Jan. 1st, 1990 to Aug. 31th, 2017. Studies including the following specific terms: "outdoor", "outside", "outdoor activity", "outside activity", "outdoor time", "outside time", and "outdoor AND measurement of time spent outdoors" were considered for this review. In total, three kinds of outdoor time measurements were discussed. Questionnaires have the longest history and are the most thoroughly revised instruments for assessing time spent outdoors, but recall bias is their most substantial drawback. Global positioning system (GPS) tracking can distinguish between indoor and outdoor locations, but its utility is limited due to several factors such as subject compatibility. Light exposure measurement devices are newly emerging, but all of these devices require good subject cooperation. Further efforts and exploration are needed to develop better methods and new tools to record exposure to the outdoors in real time. Moreover, inventing a new device by combining two or more types of devices mentioned above and using the latest technology of en ergy supplementation and autoswitching may make the best use of the advantages and bypass the disadvantages of each tool.

● **KEYWORDS:** myopia; outdoor (activity) time; questionnaire; global positioning system; light exposure
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INTRODUCTION

In recent years, myopia has become increasingly prevalent, and an unprecedented rise in myopia has occurred in East Asia, including Singapore, Japan, South Korea, Taiwan (China), Hong Kong (China) and mainland China, as well as in one country in Southeast Asia, Singapore[1]. In these regions, 80%-90% of children become myopic by the time they complete high school, and 10%-20% of all myopia cases are high myopia[1]. Other parts of the world, such as the United States, have also experienced an increase in the incidence of this condition[2]. Early onset myopia is associated with high myopia later in life, requiring expensive treatment for myopia and multiple associated sight-threatening pathologies, such as cataracts, glaucoma, retinal detachment, and myopic retinal degeneration. All of these related pathologies may ultimately lead to visual impairment and blindness[1,3-4]. Therefore, high myopia with serious complications is currently considered a significant burden to individuals, households and society[5-6]. However, knowledge of the specific pathological mechanism of myopia occurrence is limited[1]. Thus, identifying modifiable risk factors that may promote myopia onset and establishing practical and economical intervention measures are important. Generally, under the influence of environmental and genetic factors, myopia may sometimes progress into high myopia or even pathological myopia[7]. Over the past few years, scientists have shifted their attention to these environmental factors, such as near work[8-12], mid-distance activities[13-16], and outdoor activities[12,17-19]. Recent clinical trials showed that increasing the number of hours of outdoor activities could provide a protective effect against the onset of myopia[17,20-35]. Some animal experiments provided a biological explanation for this phenomenon[36-37]. Despite the discussion regarding the role of ultraviolet (UV) exposure and vitamin D, the light-dopamine pathway now seems generally accepted[38].

Two epidemiological studies, the Orinda Longitudinal Study of Myopia[17] and the 5-year-follow-up of the Sydney Myopia Study (SMS)[35], reached the conclusion that spending more time outside can help to prevent the onset of myopia. Then, two randomized controlled trials (RCTs) conducted in southern Taiwan and Shenyang, China confirmed the conclusion that increasing outdoor (activity) time can reduce the incidence of myopia[23,31]. Rose *et al*[39] have put forward a more precise point of view; they hypothesized that time spent outdoors rather than time spent playing sports per se is the crucial factor for preventing myopia after adjustment for gender, ethnicity, parental myopia, near work, parental education, and maternal employment.

Therefore, it has become particularly important to select a method to collect accurate and rigorous data on time spent outdoors or time spent performing outdoor activities when children are under natural conditions and minimize the risks of error and bias. The purposes of this review are to summarize the methods most commonly used for outdoor (activity) time data collection, particularly focusing on the steps of implementation, strengths and limitations of each method. We also propose several ideas for future data-collection strategies.

MATERIALS AND METHODS

We searched PubMed, Embase and the Cochrane Library from Jan. 1st, 1990 to Aug. 31th, 2017. The terms "outdoor", "outside", "outdoor activity", "outside activity", "outdoor time", "outside time", "outdoor AND measurement", and "outside AND measurement" in combination with "myopia", "nearsightedness", "shortsightedness", "near-sight", "near-sighted", "near-sightedness", "short-sight", "short-sighted", "short-sightedness" and "refractive error" were included in the keyword search. The reference list of each primary article identified in the initial search was scrutinized for additional potentially relevant studies. This study was conducted in accordance with the tenets of the Declaration of Helsinki and approved by the Institutional Review Board of the Shanghai General Hospital, Shanghai Jiao Tong University.

Two reviewers (Wang J and He XG) independently assessed studies for possible eligibility, and any inconsistencies were resolved by consensus. Studies were considered for inclusion in our systematic review if they were human studies that investigated the relationship between outdoor (activity) time and myopia. Studies were included if they met the following criteria: 1) outdoor activity was investigated in relation to the prevalence, incidence, or development of myopia; 2) the specific measurement of time spent outdoors was described; 3) the study was a clinical trial that evaluated the progression of myopia. The exclusion criteria were as follows: 1) no description of measurement of outdoor (activity) time; 2) duplicate data; 3) animal experiments; 4) irrelevant study cohort. For studies utilizing the same population of subjects, the most relevant study was included.

In total, 430 articles were scanned (397 records identified through databases, and 19 additional records identified through other sources), and 306 articles were retrieved after removal of duplicates. A total of 127 articles were not related to the desired topic from the title and abstract, 38 full-text articles had no particular measurement description, and 20 full-text articles did not provide the advantages and disadvantages of measuring instruments. Ultimately, 70 articles were included in our systematic review.

RESULTS

Questionnaires Questionnaires are the most commonly applied tools for data collection in studies of myopia-related factors. A variety of questionnaires have been used over the years, and most studies have produced similar results, supporting the protective effect of time spent outdoors against myopia. Some studies obtained positive results with only 1 question regarding the outdoors[12,39]. A major breakthrough in questionnaires was the SMS Questionnaire, which was able to define key questions such as the importance of time spent outdoors rather than engagement in physical activity. In addition, the SMS study was the first to conclude that time spent outdoors per se rather than time spent performing physical activities played an important role in inhibiting the onset of myopia. Therefore, the SMS Questionnaire and other questionnaires based on it, such as the Sujiatun Eye Care Study Questionnaire[40], the Singapore Questionnaire[41], and the STrabismus, Amblyopia and Refractive error in Singaporean children (STARS) study[33], have been widely used to collect data on the daily activities of children. Additionally, these questionnaires have been idiomatically translated into other languages and fine-tuned according to the particular conditions of each country[22,28,33,36,42]. In most studies, researchers calculated a concrete value for the time spent outdoors by directly asking for the number of hours in questionnaires. The time spent outdoors was summed based on the time data obtained from questionnaires completed by parents or based on data integrated from multiple questionnaires completed by parents and their children[9,12,17,20-25,27-35,39-40,43-47]. The number of hours spent outdoors per week was sometimes evaluated[9,12,17,40,46], while the quantity of outside time per day was evaluated in other questionnaires[20-21,31,47]. After the deduction of school hours and sleeping hours, there should be at most 82h remaining in a week. Thus, if the total number reported hours of activities outside school exceeded 82h per week, the data were deleted[12]. Other studies, such as RCTs, always have a long study period; in these cases, the researchers calculated the average time spent outdoors during the school year as Tschool=(Tweekday×5+Tweekend×2)/7 per day. The amount of time spent outdoors during summer and winter holidays (approximately 3mo of the year) was approximately equal to that during weekends; hence, Tyear=(Tschool×9+Tweekend×3)/12 per day[20,27].

A few studies focused on the frequency of going outdoors rather than the absolute time spent outside[23,25,29]. When evaluating the frequency of different activities, some questionnaires presented the options "often (>3 times a week and >1h each time)", "seldom", and "none"[23,25]. Because of the differences in climate and temperature between winter and summer, children tended to go outside during summer and remain indoors during winter. Considering this phenomenon, Guggenheim *et al*[29] defined the frequencies of outdoor activities according to the season as follows: a "high" amount of time spent outdoors corresponded to "3 or more hours" in summer but "more than 1h" in winter. Although the frequency outdoors could reflect the children's outdoor circumstance to some extent, but it was less accurate than recording the absolute time outdoor, although it was more likely to be remembered and had less recall bias.

Although questionnaires are widely used and continuously improving, they also have unavoidable disadvantages. 1) Most questionnaires were completed by parents due to the limitations of their children's language and reading comprehension, which inevitably caused recall errors[24-25,28-29,35,40,46]. Apart from recall bias, the estimation of average time outdoors was asked in most questionnaires, which was likely to be more difficult; 2) Because different questionnaires have different unified approaches, and the qualitative descriptions could be imprecise, the associated results were unsuitable for comparison between studies; 3) Given the suggestion from Rose *et al*[39] and animal experiment results, increased light intensity outdoors might reduce eye growth in experimental myopia[48]. However, little information about light intensity was collected using the questionnaires, and it seems impossible to evaluate light intensity with questionnaires; 4) Few studies have been conducted on the validation of questionnaires. One study on the Child Vision Care Behaviors Scale (CVCBS) reported that the total Cronbach's α coefficient was 0.842, and the total test-retest reliability was 0.644 (with an interval of 2wk), while the test-retest reliability for outdoor time was 0.530[49]. Li *et al*[50] reported that for outdoor activity, the overall intra-class correlation coefficient between two repeated surveys was 0.63 (with an interval of 3wk), and the Cronbach's α coefficient for each item was 0.61. A Cronbach's α coefficient greater than 0.7 and retest reliability greater than 0.5 were considered acceptable, which means that the validation results of the two studies were close to the edge of satisfaction. Apart from questionnaires, diaries which was similar to questionnaire were used. Some studies attempted to compare the amount of outdoor time recorded by the questionnaire/diary and sunlight exposure recorded by objective devices to test the validity of the questionnaire/diary[51-58]. There are also some unpublished trials to combine diary and questionnaire in case to get better generalized estimation. More data are required to determine the reliability and validation of the questionnaire.

Although questionnaires may be rough traditional methods, one observation that deserves comment is that most studies using questionnaires have produced similar results. This observation supports the protective effects of time spent outdoors against myopia and suggests that these effects are extremely robust as they were detected using imprecise instruments. In addition, the disadvantage in the comparability of the questionnaires mentioned above could easily be remedied by agreement on a unified questionnaire. The World Health Organization (WHO) also supported the development of a common questionnaire based on the evidence that time spent outdoors but not physical activity was a crucial factor[29]. In addition, because of their convenient, time-saving and economical characteristics[35], questionnaires are acceptable to participants and suitable for large population-based[22,24,33,35,40] and long-term[26] studies. Moreover, questionnaires can include basic information such as parental refractive error or myopia history and similar factors[9,17,23-25,27,31,33,35,40,44-45], as well as other factors in which investigators are interested. Currently, e-questionnaires are becoming increasingly popular due to the rapid development of the Internet. E-questionnaires offer a more flexible design, facilitate interaction between researchers and participants, and eliminate the need for artificial data entry and checking after the completion of paper questionnaires. Additionally, the direct completion of e-questionnaires by participants can reduce possible error in the inputting of data by researchers.

Global Positioning System Because of the above mentioned limitations of questionnaires, researchers have been seeking new methods to more objectively and accurately gather outdoor (activity) time data. Presently, global positioning system (GPS) devices show good potential to collect time-location data, especially in the field of healthcare. The GPS receiver on earth can detect a signal containing important information to determine the coordinates of its location transmitted from GPS satellites, which orbit the earth twice every 24h. The GPS signal consists of three components; each of them identifies the signal-transmitting satellite, provides the current time and date information, and relays the position separately. The GPS receiver compares the time points at which a signal is sent and received to determine the receiver location. With three or more satellites in view simultaneously, a coordinate position on earth can be calculated. If a GPS receiver detects four or more signals, altitude information can also be obtained[58].

The GPS can differentiate between indoor and outdoor conditions according to the ratio of signals detected by satellites to the total signals. When a GPS device is outdoors, more satellites can communicate with it; thus, a stronger signal can be received. In contrast, when the GPS device is indoors, a weak signal or no signal is received due to the shielding effect of the building[59]. Tandon *et al*[60] assessed the reliability of GPS in distinguishing between indoor and outdoor locations, considering direct observation for 2d as the gold standard. According to receiver operating characteristic analyses and *t*-tests, GPS showed excellent performance in distinguishing between outdoor and indoor locations[60]. Pearce *et al*[61] and Cooper *et al*[62] used accelerometer-matched GPS data to distinguish between indoor and outdoor locations (Figure 1). When a particular time bin of accelerometer data did not correspond to a GPS record, the time bin was defined as indoors; each time bin of matched accelerometer and GPS data was defined as outdoors.

With advancements in technology, GPS devices have decreased in size and price, and battery life has increased[58,63]. The strengths of this device include objectivity[64], high temporal resolution[58,63,65-66], little bias[65], suitability for a large sample size[62,64], and ability to record multidimensional data[64]. The reported sensitivity and specificity of the GPS tracking method for distinguishing between indoor and outdoor locations were 82% and 88%, respectively, considering direct observation as the gold standard[60]. Wu *et al*[66] have reported higher sensitivity and specificity of classification of location using their method (indoor: sensitivity >91%, specificity >80%, and precision >96%; vehicular travel: sensitivity >71%, specificity >99%, and precision >88%). Additionally, GPS signals can be detected in almost all weather conditions and environments. Thus, GPS devices can be used to study a wide range of variables, such as energy expenditure[67-68] and air pollutant exposure[69]. Furthermore, GPS devices may be a useful tool in studies of the control of myopia in children and in public health programs.

However, this method has some shortcomings. First, because changes in location between indoors and outdoors or changes in motion state may occasionally fail to be detected by a GPS receiver[57,67-68], the sensitivity of GPS was not as high as we expected. Second, GPS signals can be shielded by dense tree canopies, reflected by nearby construction or other reflective surfaces such as metal or big water reservoirs, disturbed by ionization or the atmosphere[61,64], or disrupted by power substation transformers or microwave ovens[55]. Third, these signals cannot measure light intensity. Researchers tend to use GPS accompanied by geographical information system (GIS)[55,64], an accelerometer[59,61,64-65], or a diary/questionnaire[59,62-63] to solve these problems. To our knowledge, other researchers are trying to use GPS to improve the overall accuracy of the light sensor method. These tactics may solve these problems to some extent. With the development of technology, the start-up time of GPS will be reduced, and the sensitivity for detecting position changes can be improved. These improvements can make the application value of GPS more significant.

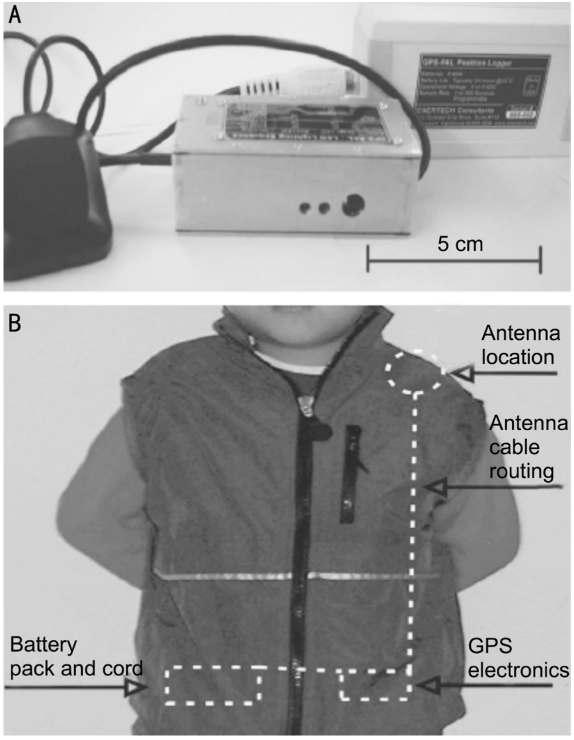

Figure 1 GPS device and dressing diagram A: The GPS package, contains antenna, electronics, and battery from left to right; B: How a child wears GPS-PAL in a vest. Dashed lines indicate location of components inside the vest[63].

Light Exposure Measurement Light exposure measurement, another method that can distinguish between indoor and outdoor locations, can provide more detailed information about the frequency, intensity and duration of light exposure, indicating outdoor exposure. There are two different strategies of measuring illumination intensity. One strategy is to use a wearable device that detects light and records the associated data, and the other strategy is to record UV light *via* conjunctival ultraviolet autofluorescence (UVAF) photography.

Wearable Light Sensor Device The HOBO Pendant Temperature/Light Data Logger[38] is a portable and waterproof device with a core composed of a light sensor that records the time and luminance of white light in lux (1 lumen per square meter). Dharani *et al*[38] asked a group of children to wear the light meter for 7d. Simultaneously, an outdoor diary (an adaptation of the Child Development Supplement-III 2007) was structured to track and note down the type of activities and detail the start and end time of each activity from 7 a.m. to 7 p.m. It was found that the light intensity was generally <1000 lx indoors but varied from a few thousand to tens of thousands of lux outdoors. Because the light meter was an objective device, the data from the light meter could be used to verify the accuracy of data from an activity diary[38]. Another light meter, the Actiwatch 2[70], combines a silicone photodiode light sensor and a solid-state piezoelectric accelerometer to measure light illuminance and physical activity separately. The correlation between the Actiwatch 2 device and a standard light meter was high, with inter-device intra-class correlation coefficients of 0.99 for the light data and 0.98 for the accelerometry data[70]. The major finding of the study was that emmetropic children had greater light exposure than myopic children[70], and this finding was consistent with previous studies drawing the conclusion that spending time more outdoors can prevent the onset and progression of myopia[17,20,23,31,35,39]. Moreover, the researchers noted that illuminance greater than 2000 lx was strongly, independently, significantly associated with refractive error[70].

Conjunctival Ultraviolet Vutofluorescence Conjunctival UVAF is another novel method used to monitor exposure to the outdoors. To date, only two studies have reported using UVAF to calculate the time spent outdoors and its relationship with myopia[71-72]. Conjunctival UVAF was first developed to detect preclinical ocular surface sunlight-induced UV damage[73]. In response to UV radiation, especially UV-B and UV-C, the ocular surface may undergo various changes at the cellular level, including suppression of mitosis, nuclear disruption, eosinophilic staining, failure of cellular adhesion[74], and changes in immune-related activity, that might damage epithelial or stem cells[75-76]. These alterations can be recorded and analyzed to calculate the level of outdoor exposure. Digital photographs were captured by passing light through UV transmission filters as well as infrared and UV barrier filters to record fluorescent light only[71,75,77]. Separate views of the nasal and temporal regions of each eye were photographed. The sum of the area in the four captured photographs (both the nasal and temporal photographs of each eye) was referred to as "Total UVAF". The results of two studies consistently showed the high intra- and inter-observer reliability of UVAF. A newly published study[78] used a commercial software package (MATLAB; www.mathworks.com) to determine the area as well as the intensity of the captured fluorescence. Kearney *et al*[78] first outlined an area encompassing the fluorescence. Then, they used an algorithm created with MATLAB to determine a pixel threshold. The algorithm provided an automated means of differentiating fluorescence from non-fluorescence within the outlined area. Finally, the conjunctival UVAF pixel area was converted to square millimeter using an algorithm that accounted for camera magnification. Kearney *et al*[78] then used two matrices to explore conjunctival UVAF intensity, average conjunctival UVAF pixel intensity per square millimeter and total conjunctival UVAF pixel intensity across the fluorescing area. The average pixel intensity value can discriminate between subjects with small bright areas and those with large dim areas of conjunctival UVAF because it determines the pixel intensity per unit area of conjunctival UVAF.

One article reported UVAF results in increments of 10-mm^2 area and showed that intra- and inter-observer reliability were "very good" (κ=0.81) and "good" (κ=0.71), respectively[71]. The other article reported that intra- and inter-observer reliability were 0.988 and 0.924, respectively[72]. Sherwin *et al*[71] designed a study to determine the reliability of UVAF measurement and its relationship with outdoor activity. The study showed an excellent correlation between conjunctival UVAF-based and questionnaire-based outdoor activity levels, especially for the median UVAF, which can be considered a biomarker of outdoor exposure[71]. In addition, both conjunctival UVAF area and intensity are positively associated with self-reported time spent outdoors[78]. These studies presented the hypothesis that increasing UVAF can protect against myopia and that the protective effect of increased UVAF against myopia could even be stronger than that of increased time spent outdoors[72].

However, UVAF has several limitations. First, UVAF is a form of cumulative recording of exposure, but we do not know how fast UVAF accumulates and how fast it decays; this issue may result in erroneous estimates of outdoor time. Second, what the area of UVAF represents remains unclear, although extracellular matrix density[70] and cellular activity[76] have been hypothesized. Third, this method is a type of medical examination (disliked by children); thus, subject compliance is not ideal and unsuitable for large-sample studies.

DISCUSSION

This review summarizes three representative methods measuring time spent outdoors or spent on outdoor activities and listed the advantages and disadvantages of each impersonally. Questionnaires can be used in large population-based studies and show relatively good compliance, but they can have recall errors and reporting bias. E-questionnaires presented on computers or mobile apps are becoming increasingly common for the collection of questionnaire-based data as they display greater efficiency and quality than paper questionnaires. GPS receivers can provide objective data reflective of indoor or outdoor location. Moreover, combining GPS with other methods may increase the validity and accuracy of the data, but the accuracy of GPS devices requires further improvement. Conjunctival UVAF is innovative and shows high reliability. However, UVAF devices contact the eye, which is a major limitation. Monitoring UV exposure does not only depend on conjunctival UVAF but can also be achieved with objective measurement devices. Light meters are objective devices and are clearly preferable, but they must be directly exposed to light and not covered by clothing. Thus, all these wearable devices require improvements to increase subject compliance.

Since the evidence has demonstrated that increasing outdoor activities can inhibit the onset of myopia, more attention should be paid to factors accounting for improvements in the effectiveness of outdoor interventions in future research.

Current efforts and explorations have been searching for better or more integrated methods, as well as new tools for real-time recording of time spent outdoors. To our knowledge, two recently developed spectacle-mounted devices, Clouclip (www.clouclip.com, Hangzhou, China) and AKESO (Eyecare Ltd., China), have already appeared in the Chinese market and were developed by Aier Eye Hospital Group and Beijing Tongren Hospital, respectively. Both devices are combined with glasses (external or built-in) to collect light intensity data to estimate the amount of outdoor time and help to monitor near-work status. In addition, the recording data can be uploaded through a supporting app in real time. With the globalization of myopia and the development of science and technology, the creation of new methods to measure myopia-related risk factors and conducting more effective interventions to slow the onset and progression of myopia will make continuous remarkable progress. We can expect results from new equipment (including but not limited to Clouclip and AKESO), and more precise outdoor time data and outdoor light intensity data will emerge in the next few years.

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