BMJ Open Ophthalmology

Effect of mount location on the quantification of light intensity in myopia study

Longbo Wen,[1,2] Hong Liu,[1,2] Zhao Chen,[1,2] Qinglin Xu,[1,2] Ziqi Hu,[2] Weizhong Lan,[1,3] Zhikuan Yang[1,2]

To cite: Wen L, Liu H, Chen Z, *et al*. Effect of mount location on the quantification of light intensity in myopia study. *BMJ Open Ophthalmology* 2023;**8**:e001409. doi:10.1136/bmjophth-2023-001409

Received 21 July 2023
Accepted 19 December 2023

Check for updates

[1]Aier School of Ophthalmology, Central South University, Changsha Aier Eye Hospital, Aier Eye Hospital Group, Changsha, China
[2]Hunan Province Optometry Engineering and Technology Research Center, Changsha, China
[3]Guangzhou Aier Eye Hospital, Jinan University, Guangzhou, Guangdong, China

Correspondence to
Weizhong Lan; lanweizhong@aierchina.com and

Zhikuan Yang; 13380071988@189.cn

ABSTRACT

Purpose To investigate how the mounting location of wearable devices affects the measurement of light intensity.

Methods Two commercially available wearable devices, HOBO and Clouclip, were used to compare the effects of different mount locations on light intensity measurement. We assessed the consistency of the measurements of the two devices by placing a HOBO and a Clouclip simultaneously in 26 different light environments and measuring the light intensity. To simulate the real-life usage scenarios of the two devices, we had 29 participants wear two HOBOs—one on the wrist and the other on the chest—along with a Clouclip on their spectacles for 1 day; meanwhile, the light intensity was measured and analysed.

Results When under the same light environments, the light intensity measured by the Clouclip was 1.09 times higher than that by the HOBO, with an additional 82.62 units (r^2=1.00, p<0.001). When simulating the real-life scenarios, the mean light intensity at the eye-level position was significantly lower than that at the chest position (189.13±665.78 lux vs 490.75±1684.29 lux, p<0.001) and the wrist position (189.13±665.78 lux vs 483.87±1605.50 lux, p<0.001). However, there was no significant difference in light intensity between the wrist and chest positions (483.87±1605.50 lux vs 490.75±1684.29 lux, p=1.00). Using a threshold of 1000 lux for outdoor exposure, the estimated light exposure at the eye-level position was significantly lower than that at the chest position (3.9% vs 7.8%, χ^2=266.14, p<0.001) and the wrist position (3.9% vs 7.7%, χ^2=254.25, p<0.001).

Conclusions Our findings revealed significant variations in light exposure among the wrist, chest and eye position. Therefore, caution must be exercised when comparing results obtained from different wearable devices.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Researchers widely recognise the importance of objectively quantifying environmental factors in myopia research. However, direct comparison of results between different studies is hindered by variations in the mounting locations and measuring angles of existing objective measurement devices.

WHAT THIS STUDY ADDS

⇒ This study contributes by using objective data to reveal differences in perceived light intensity at the eye, chest and wrist levels.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Considering the variations in mounting locations and measuring angles among different objective measurement devices, it is necessary to establish distinct light intensity thresholds for distinguishing between indoor and outdoor environments.

INTRODUCTION

The huge increase in the prevalence of myopia among East Asians in the last few decades is commonly attributed to lifestyle changes.[1 2] In various parts of the world, children's lifestyles have shifted from outdoor dominated to indoor dominated.[3] Extensive and consistent evidence suggests that increased outdoor time is effective in preventing the onset of myopia, primarily due to the high light intensity.[4–6] Only a few studies have failed to confirm the association.[7 8] However, a major challenge in this area has been how to quantify the light intensity while spending time outdoors objectively and accurately.

With the advancement of wearable technologies, numerous devices embedded with light sensors have been developed to measure light intensity. The initial device used to quantify daily light intensity is HOBO (Contoocook, New Hampshire, USA), typically worn in front of the chest for monitoring, followed by wrist-worn watches known as Actiwatch (Philips Respironics, Pittsburgh, Pennsylvania, USA) or Fitsight (coinventors: SSM, SHP, ZXQ, Singapore).[9–11] However, it should be noted that the light intensity measured by these devices may differ from what is perceived by the eye, as their measurement angles do not align with the participant's line of sight. Recently, a spectacle-mounted device called Clouclip (Glasson Technology Co, Hangzhou, China) was developed to measure eye-level light intensity approximately along the line of sight.[12] Therefore, it is reasonable to assume that studies employing these devices to quantify outdoor time may yield incomparable results due to variations in mounting positions and survey angles.

In the Family Incentive Trial, Singaporean children's reported time spent outdoors was measured using HOBO hung in front of their chests. The average outdoor time recorded was 61±40 min when the threshold light intensity for outdoor activity was set at 1000 lux.[13] In contrast, the outdoor exposure time of children from the Growing Up in Singapore Towards Healthy Outcomes birth cohort was measured using the wrist-worn device Fitsight. The data collected indicated an average outdoor time of only 37±19 min, using the same threshold lux level for outdoor activity.[14] This significant difference in outdoor exposure between the two studies may be attributed to variations in the participants' lifestyles. Additionally, the different positions and angles at which the two devices were worn could have influenced the quantification of outdoor time.

In this study, we conducted a comparison of light intensity measured at three distinct locations: the wrist, chest and eye level to facilitate a comprehensive interpretation of research findings that employ various wearable devices for collecting light intensity data.

METHODS

All participants in this study were recruited from the staff of Changsha Aier Eye Hospital. Patients or the public WERE NOT involved in the design, or conduct, or reporting, or dissemination plans of our research.

Two commercial devices were used in the study. The HOBO, a commonly suspended light metre placed in front of the chest, was used to record the light intensity in lumens per square foot (lum/ft^2) at a frequency of one measurement per minute.[9] On the other hand, the Clouclip, which is equipped with a light sensor and attached to the right arm of the eyeglasses, recorded the light intensity in lux at a frequency of one measurement every 2 min. Detailed specification and validation tests have been reported previously.[12]

Initially, we conducted an experiment to determine if there were any disparities in the measurements of light intensity between the HOBO and Clouclip, as well as between the two HOBO devices. To achieve this, we initially placed the Clouclip and one HOBO in 26 different light environments ranging from 100 to 26 242 lux. Subsequently, we placed the two HOBO devices in the same 26 light environments. For each light environment, we performed five measurements using each device. Subsequently, we calculated the average value of the five readings for comparison purposes.

After confirming the measurement discrepancy between the two devices, all participants were requested to wear two HOBOs and one Clouclip simultaneously for the duration of 1 day (figure 1). This measurement was taken to collect data regarding the light intensity exposure on the wrist, chest and eye positions. Specifically, a HOBO device was affixed to the dorsal side of the left wrist using a custom-made elastic strap, at the same position as a traditional wristwatch. For participants wearing full sleeves, we asked that the elastic strap to be tied over the sleeves. Participants were instructed to regularly monitor the positioning of the HOBO every 10 min, ensuring it remained consistently placed on the back of the hand with its light sensor facing outward. Furthermore, participants were required to ensure that their entire bodies remained in the homogeneous ambient light environment. For example, participants were not permitted to extend their wrists outside a window while indoors. Following the experiment, we employed a simple questionnaire to inquire whether the participants had conducted regular checks in accordance with our guidelines. Additionally, we will analyse the collected data. For instance, if the data indicate that a subject has been in a very dim environment for an extended period, we will investigate and verify this through phone communication. The other HOBO was pinned to the coat to ensure that the light sensor was constantly facing outward. Additionally, a Clouclip was attached to the right arm of the participants' spectacles. For those who did not wear spectacles, frames without lenses were provided, so that the Clouclip could be worn. The data were collected from 22 April 2020 to 15 July 2020, which included 10 rainy days, 13 cloudy days and 6 sunny days. The variety of weather conditions provided a considerable range of light scenarios for testing. During the wearing period, participants were encouraged to wear the Clouclip throughout the day, excluding bathing and sleeping times. They were also encouraged to continue with their habitual activities as usual. HOBO and Clouclip were set to start and end the data collection at the same time. Both the HOBO and Clouclip devices were set to initiate and conclude the data collection simultaneously.

Data processing and statistical analysis

Once the participants completed the 1-day wear of the devices, the light intensity values measured by the HOBO and Clouclip were downloaded as Excel files for each individual participant. Due to the difference in units between the two devices, we performed a unit conversion to make the data comparable by using the equation 1 lum/ft^2=10.76 lux. Additionally, there was a disparity in the frequency of data collection between the HOBO and Clouclip. To align the data collected by both devices, we calculated the average of the HOBO data at 2-minute intervals. Afterwards, we determined the effective wearing time of each participant based on the number of data input that were one-to-one matched on the acquisition time collected by each participant's three instruments. Subsequently, we calculated the proportion of time during which the light intensity exceeded 1000 lux in relation to the total recording time at the wrist, chest and eye levels, respectively.

The results are presented as mean±SD. Statistical analyses were performed using SPSS V.25.0. For the device

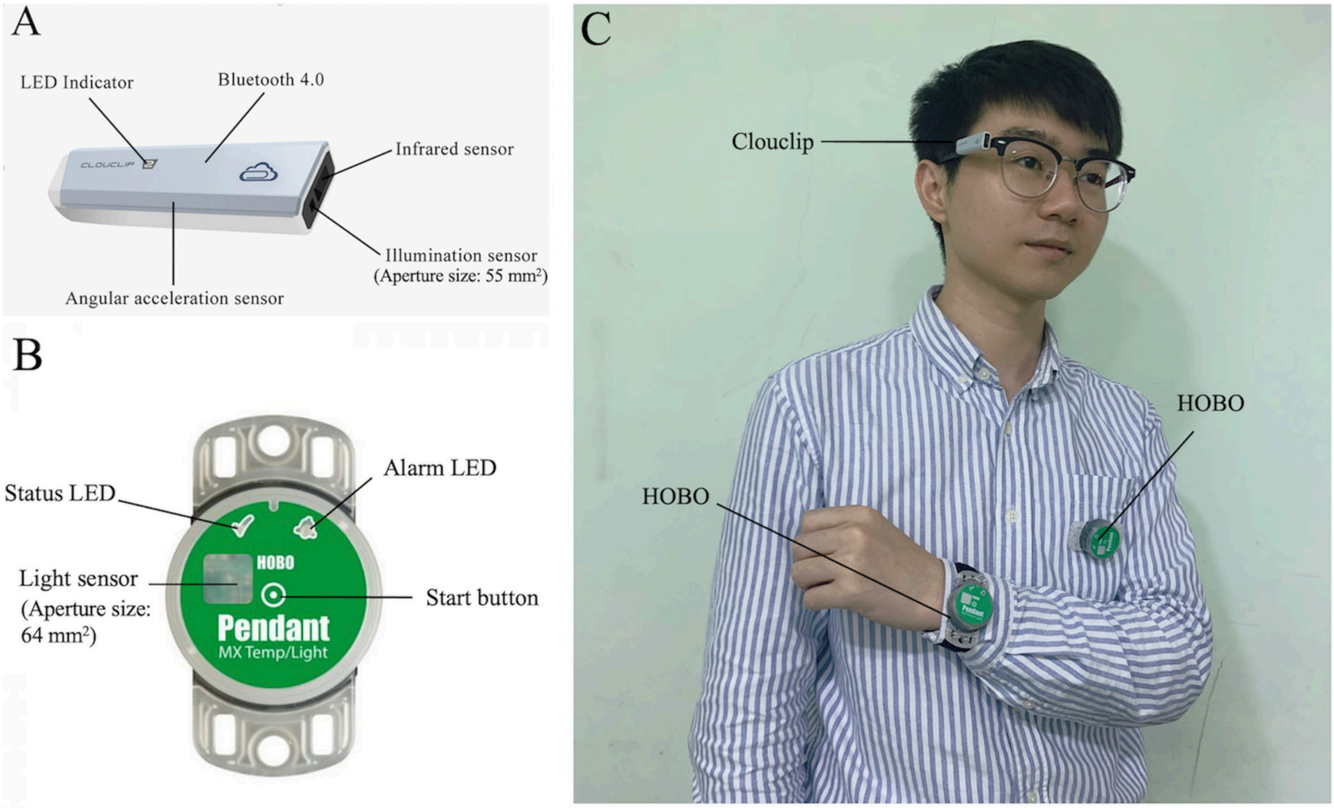

Figure 1 (A) Location of the sensors in Clouclip. (B) Location of the sensors in HOBO. (C) One participant who wore a HOBO on the left wrist, a HOBO on the coat and a Clouclip on the right arm of spectacle.

comparison, a paired t-test was conducted to assess the differences in light intensity measured by HOBO and Clouclip, as well as by the two HOBO devices. Additionally, linear regression was employed to establish the correlation between the two devices. Subsequently, the differences in illumination received at the wrist, chest and eye levels were compared using a one-way analysis of variance (ANOVA). As a threshold of 1000 lux was adopted to evaluate outdoor activity, the proportions of light intensity surpassing 1000 lux in the three different positions were compared using a X^2 test. Further pairwise comparisons were performed using Bonferroni correction. Moreover, the difference in light intensity between different positions under the condition of ambient illumination ≥1000 lux or <1000 lux was assessed using a two-independent samples t-test. The difference was considered statistically significant when $p<0.05$.

RESULTS

General characteristics

A total of 29 participants with a mean age of 27.27±3.37 years (range: 21–36 years) were included in the study, of whom 14 (48.28%) were male and 15 (51.72%) were female. Overall, the compliance of all participants in terms of wearing HOBO and Clouclip was satisfactory, with a mean effective wearing time of 11.11±3.31 hours.

Comparison between HOBO and Clouclip, as well as between two HOBOs

A significant difference was found in the average measured light intensity between HOBO and Clouclip. The measurements obtained by Clouclip were greater than those obtained by HOBO (5202±6786 lux vs 4677±6199 lux, $p<0.001$). Despite this significant difference, both devices showed a high correlation in their readings ($r=1.00$, $p<0.001$; figure 2). Further analysis using linear regression revealed that the measured value of the Clouclip was approximately 1.09 times higher than that of the HOBO, plus an offset of 82.62 ($r^2=1.00$, $p<0.001$). Conversely, the variance in average measured light intensity between the two HOBO devices was not statistically significant (4692±6212 lux vs 4677±6199 lux, $p=0.07$), with an inter-HOBO correlation coefficient for light intensity of 1.00.

Comparison of light intensity measured at the wrist, chest and eye level

One-way ANOVA revealed significant differences in light intensity among the wrist, chest and eye levels ($F=290.38$, $p<0.001$). Pairwise comparisons demonstrated that the light intensity measured at the eye level was significantly lower than at the chest level (189±666 lux vs 491±1684 lux, $p<0.001$) and the wrist level (189±666 lux vs 484±1606 lux, $p<0.001$). The difference in light

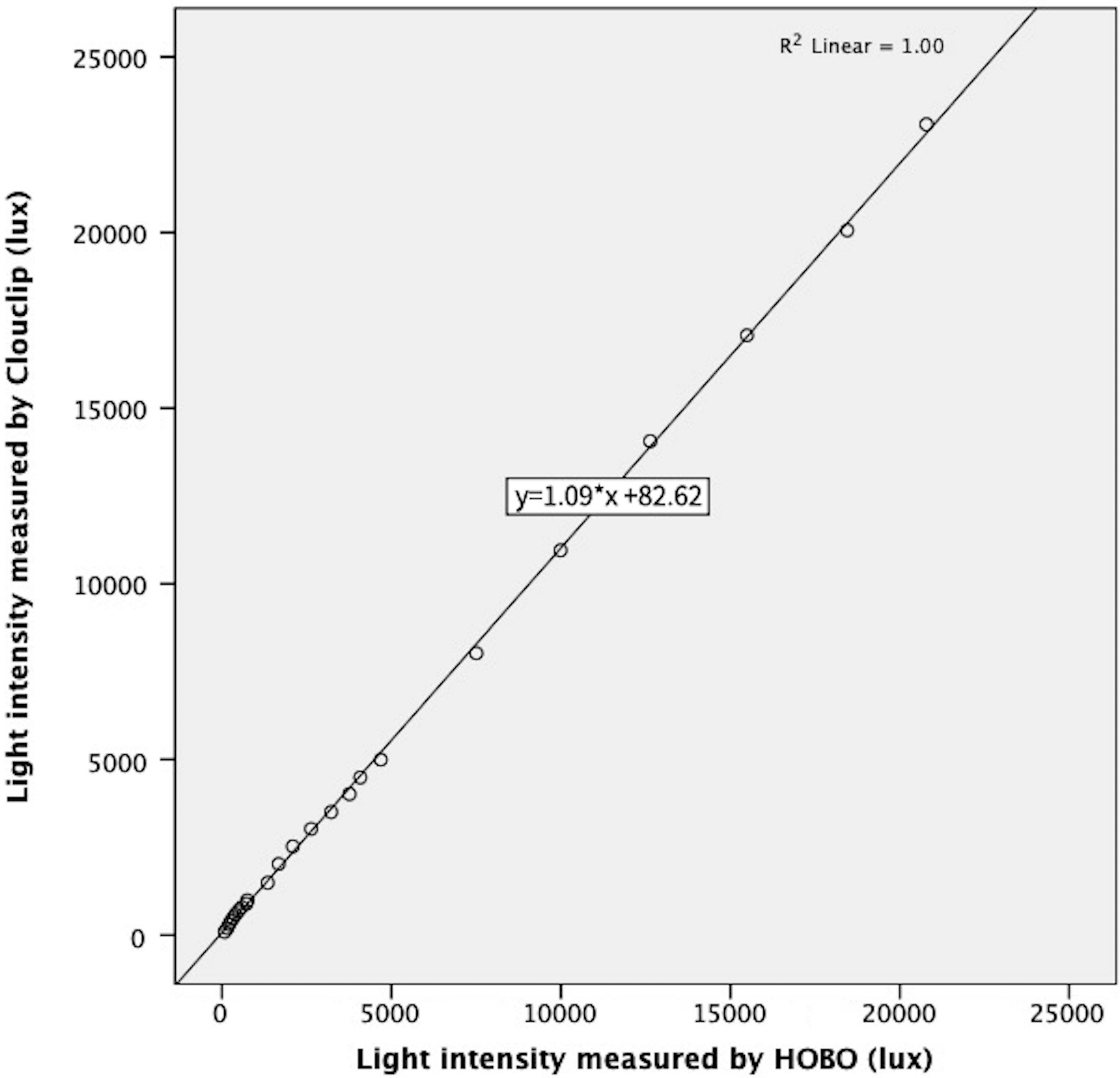

Figure 2 Correlation of light intensity measured by HOBO and Clouclip.

intensity between the eye level and chest level ranged from −10239 to 28646 lux, while the difference between the eye level and wrist level ranged from −10 957 to 32671 lux. However, there was no significant difference in light exposure between the wrist level and chest level (484±1606 lux vs 491±1684 lux, p=1.00). The range of the difference in light intensity between the wrist level and chest level was −21 514 to 17667 lux. As shown in figure 3, the light intensity perceived at the eye level was approximately 0.28 times than that perceived at the wrist level plus 54.62 (r^2=0.45, p<0.001), and 0.28 times that that perceived at the chest level plus 50.80 (r^2=0.51, p<0.001), respectively.

Comparison of the proportion of time when light intensity >1000 lux between wrist, chest and eye level

Previous studies have set the cut-off value for light intensity to distinguish between indoor and outdoor environments at 1000 lux, regardless of whether the light intensity was measured at the wrist, chest or eye level.[9 10 12] In this study, there was a significant difference in the proportion of time during which the light intensity exceeded 1000 lux compared with the entire recording time among the wrist, chest and eye levels (χ^2=314.70, p<0.001). The pairwise comparison revealed that the proportion of time at the eye level was significantly lower than that at the chest level (3.9% vs 7.8%, χ^2=266.14,

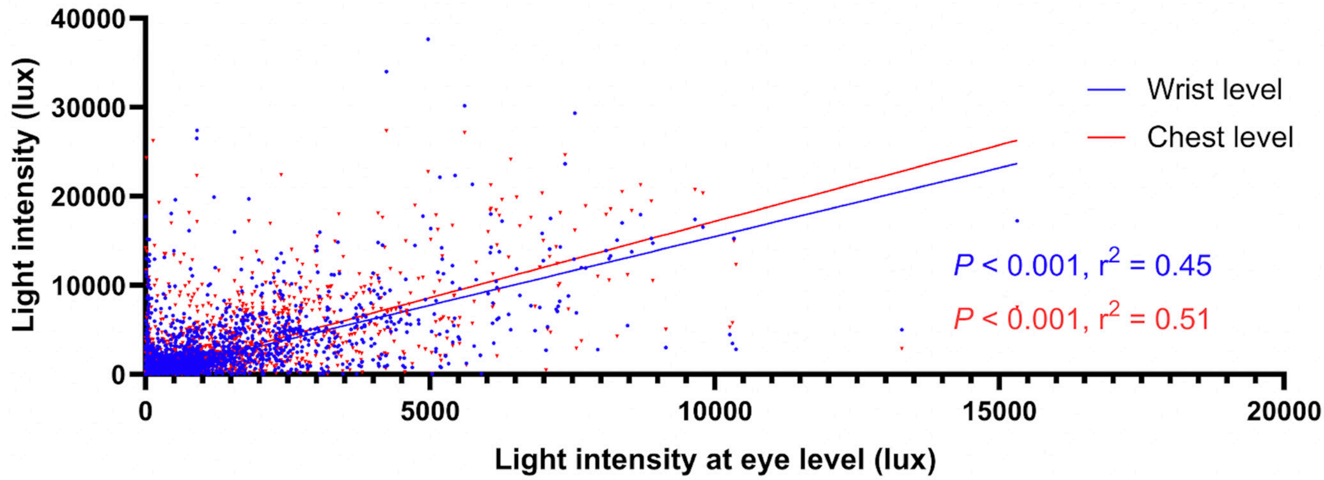

Figure 3 Correlation between light intensity perceived at wrist level and eye level, as well as between light intensity perceived at chest level and eye level.

p<0.001), as well as significantly lower than that at the wrist level (3.9% vs 7.7%, χ^2=254.25, p<0.001). However, there was no significant difference in proportion between the wrist and chest levels (7.7% vs 7.8%, χ^2=0.15, p=0.70).

DISCUSSION

The use of wearable light intensity-measuring devices, such as the chest-hung HOBO, wrist-worn Actiwatch or FitSight, and spectacle-mounted Clouclip, is becoming increasingly common in myopia research. However, a challenge arises when interpreting and comparing results from different studies that employ different devices to quantify light intensity. Since measurements are taken from different positions and angles, direct comparison of results is unreasonable. In this study, we compared the differences in perceived light intensity at the wrist, chest and eye levels, and found that the eye level perceived significantly lower light intensity compared with the wrist and chest levels.

Interestingly, we observed that the light intensity at the eye level was significantly lower than at the wrist and chest levels, but there was no difference between the wrist and chest levels. We speculate that the underlying reason might be that the participants tended to have a slightly downward head position during their daily activities, which caused the Clouclip to perceive less light input compared with other devices due to the different angle. In line with the light intensity comparison, the proportion of time during which light intensity exceeded 1000 lux relative to the entire recording time was also much lower at the eye level compared with the wrist and chest levels. This suggests that setting 1000 lux as the threshold for distinguishing indoor and outdoor environments when measuring light intensity at the eye level is not appropriate. Instead, a lower threshold should be warranted. A recent study shows that the protective effect of outdoor time is not only related to the duration of exposure, but also to the light intensity.[15] Exposure to bright light can elevate dopamine levels in the retina, subsequently inhibiting the progression of myopia.[16] The release of dopamine is regulated by the light intensity. This finding suggests that collecting the eye-level light intensity can help elucidate the details and mechanisms of outdoor time to protect myopia. Therefore, we recommend that the eye-level light intensity should be measured in the future studies.

Few studies have explored the influence of measurement positions and angles on light intensity assessment. A previous study by Okudaira *et al* used two light transducers to investigate the disparity in light exposure between the eye level and wrist level, revealing a strong correlation between light exposure at these two locations.[17] However, due to limitations in the measurement range of the light transducer, they could only collect light intensity data within 2500 lux; hence, the differences under high light intensity conditions were not captured. Additionally, the authors did not specify the specific differences between the eye level and wrist level. In this study, we collected light intensity data nearing 40 000 lux, facilitating a comprehensive comparison of light intensity variations across different locations under high light exposure conditions. The largest difference identified in our study was up to 32 671 lux.

There are several limitations that should be noted in this study. First, despite our efforts to rectify the difference between Clouclip and HOBO devices, it is possible that the use of two different devices to collect light intensity data could still impact the results. Second, the findings would be more persuasive if the participants represented a wider age range, had more diverse occupations and were observed over a longer time. Third, we did not investigate the appropriate light intensity threshold for distinguishing between indoor and outdoor settings at eye level, wrist level and chest level. This issue necessitates further exploration in future research.

In summary, our study identified significant variations in light exposure between the eye, wrist and chest levels, particularly highlighting the disparities between the eye level and wrist level, as well as chest level. These findings imply that when using different wearable devices to measure outdoor time in future studies, it is crucial to establish appropriate light intensity thresholds for distinguishing indoor and outdoor environments based on the specific acquisition position and angle.

Acknowledgements All participants for their interest in the study should be thanked.

Contributors Planning—LW, WL and ZY. Conducting—HL, ZC, QX and ZH. Conception—LW. Data acquisition—ZC, QX and ZH. Data analysis and interpretation—HL and LW. Supervision—WL and ZY. Writing (original draft)—LW. Writing (review and editing)—LW, HL, WL and ZY. Guarantor—WL.

Funding This study was supported by a grant from the Natural Science Foundation of Hunan Province, China (grant no. 2022JJ40002).

Disclaimer The funder had no role in the design and conduct of the study; collection, management, analysis and interpretation of the data; preparation, review or approval of the manuscript; and decision to submit the manuscript for publication.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study involves human participants, complied with the Helsinki Declaration and was approved by the Ethics Committee of Aier Eye Hospital Group (no. IRB2017005). Before the study commenced, written informed consent was obtained from all participants.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iD

Weizhong Lan http://orcid.org/0000-0002-3829-7415

REFERENCES

1 Rudnicka AR, Kapetanakis VV, Wathern AK, *et al*. Global variations and time trends in the prevalence of childhood myopia, a systematic review and quantitative meta-analysis: implications for Aetiology and early prevention. *Br J Ophthalmol* 2016;100:882–90.
2 Morgan IG, Wu P-C, Ostrin LA, *et al*. IMI risk factors for myopia. *Invest Ophthalmol Vis Sci* 2021;62:3.
3 Zadnik K, Mutti DO. Outdoor activity protects against childhood myopia-let the sun shine in. *JAMA Pediatr* 2019;173:415–6.
4 Xiong S, Sankaridurg P, Naduvilath T, *et al*. Time spent in outdoor activities in relation to myopia prevention and control: a meta-analysis and systematic review. *Acta Ophthalmol* 2017;95:551–66.
5 Deng L, Pang Y. Effect of outdoor activities in myopia control: meta-analysis of clinical studies. *Optom Vis Sci* 2019;96:276–82.
6 Ho CL, Wu WF, Liou YM. Dose–response relationship of outdoor exposure and myopia indicators: A systematic review and meta-analysis of various research methods. *Int J Environ Res Public Health* 2019;16:2595.
7 Lu B, Congdon N, Liu X. Associations between near work, outdoor activity, and myopia among adolescent students in rural china [Study report no.2]. *Arch Ophthalmol* 2009;127:769.
8 Low W, Dirani M, Gazzard G, *et al*. Family history, near work, outdoor activity, and myopia in Singapore Chinese preschool children. *Br J Ophthalmol* 2010;94:1012–6.
9 Dharani R, Lee C-F, Theng ZX, *et al*. Comparison of measurements of time outdoors and light levels as risk factors for myopia in young Singapore children. *Eye (Lond)* 2012;26:911–8.
10 Read SA, Collins MJ, Vincent SJ. Light exposure and physical activity in myopic and Emmetropic children. *Optometry and Vision Science* 2014;91:330–41.
11 Verkicharla PK, Ramamurthy D, Nguyen QD, *et al*. Development of the Fitsight fitness Tracker to increase time outdoors to prevent myopia. *Transl Vis Sci Technol* 2017;6:20.
12 Wen L, Cheng Q, Cao Y, *et al*. The Clouclip, a Wearable device for measuring near-work and outdoor time: validation and comparison of objective measures with questionnaire estimates. *Acta Ophthalmol* 2021;99:e1222–35.
13 Ngo CS, Pan C-W, Finkelstein EA, *et al*. A cluster randomized controlled trial evaluating an incentive-based outdoor physical activity programme to increase outdoor time and prevent myopia in children. *Ophthalmic Physiol Opt* 2014;34:362–8.
14 Li M, Lanca C, Tan C-S, *et al*. Association of time outdoors and patterns of light exposure with myopia in children. *Br J Ophthalmol* 2023;107:133–9.
15 He X, Sankaridurg P, Wang J, *et al*. Time outdoors in reducing myopia: A school-based cluster randomized trial with objective monitoring of outdoor time and light intensity. *Ophthalmology* 2022;129:1245–54.
16 Ashby RS, Schaeffel F. The effect of bright light on lens compensation in chicks. *Invest Ophthalmol Vis Sci* 2010;51:5247–53.
17 Okudaira N, Kripke DF, Webster JB. Naturalistic studies of human light exposure. *Am J Physiol* 1983;245:R613–5.