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Title:

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Date:

2017-05

Citation:

Verkicharla, P. K., Ramamurthy, D., Quang, D. N., Zhang, X., Pu, S. -H., Malhotra, R., Ostbye, T., Lamoureux, E. L. & Saw, S. -M. (2017). Development of the FitSight Fitness Tracker to Increase Time Outdoors to Prevent Myopia. TRANSLATIONAL VISION SCIENCE & TECHNOLOGY, 6 (3), <https://doi.org/10.1167/tvst.6.3.20>.

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Article

Development of the FitSight Fitness Tracker to Increase Time Outdoors to Prevent Myopia

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Received: 28 October 2016

Accepted: 19 March 2017

Published: 16 June 2017

Keywords: fitness tracker; FitSight; myopia; light illuminance level; time outdoors

Citation: Verkicharla PK, Ramamurthy D, Nguyen QD, Zhang X, Suan-Hi P, Rahul M, Truls O, Ecosse LL, Seang-Mei S. Development of the FitSight fitness tracker to increase time outdoors to prevent myopia. *Trans Vis Sci Tech.* 2017;6(3):20, doi: 10.1167/tvst.6.3.20

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Purpose: To develop a fitness tracker (FitSight) to encourage children to increase time spent outdoors. To evaluate the wear pattern for this tracker and outdoor time pattern by estimating light illumination levels among children.

Methods: The development of the FitSight fitness tracker involved the designing of two components: (1) the smartwatch with custom-made FitSight watch application (app) to log the instant light illuminance levels the wearer is exposed to, and (2) a companion smartphone app that synchronizes the time outdoors recorded by the smartwatch to smartphone via Bluetooth communication. Smartwatch wear patterns and tracker-recorded daily light illuminance levels data were gathered over 7 days from 23 Singapore children (mean \pm standard deviation age: 9.2 \pm 1.4 years). Feedback about the tracker was obtained from 14 parents using a three-level rating scale: very poor/poor/good.

Results: Of the 14 parents, 93% rated the complete “FitSight fitness tracker” as good and 64% rated its wearability as good. While 61% of 23 children wore the watch on all study days (i.e., 0 nonwear days), 26% had 1 nonwear day, and 4.5% children each had 3, 4, and 5 nonwear days, respectively. On average, children spent approximately 1 hour in light levels greater than 1000 lux on weekdays and 1.3 hours on weekends (60 \pm 46 vs. 79 \pm 53 minutes, $P = 0.19$). Mean number of outdoor “spurts” (light illuminance levels >1000 lux) per day was 8 \pm 3 spurts with spurt duration of 34 \pm 32 minutes.

Conclusion: The FitSight tracker with its novel features may motivate children to increase time outdoors and play an important role in supplementing community outdoor programs to prevent myopia.

Translational Relevance: If the developed noninvasive, wearable, smartwatch-based fitness tracker, FitSight, promotes daytime outdoor activity among children, it will be beneficial in addressing the epidemic of myopia.

Introduction

Myopia is a significant public health problem worldwide.^{1–5} The epidemic of myopia has led to a huge economic burden due to ophthalmic consultations and optical purchases.^{6,7} The significant increase in the prevalence of myopia in urban Asian cities over recent generations indicates a possible major environ-

mental influence on myopia.⁸ Recent evidence from animal models^{9–15} and human studies have shown associations between outdoor time and myopia, suggesting that time spent outdoors could be an important modifiable risk factor for myopia.^{16–20} In the Guangzhou Outdoor Activity Longitudinal study, the 3-year cumulative myopia incidence in 7- to 9-year-old Chinese children was lower among those who had

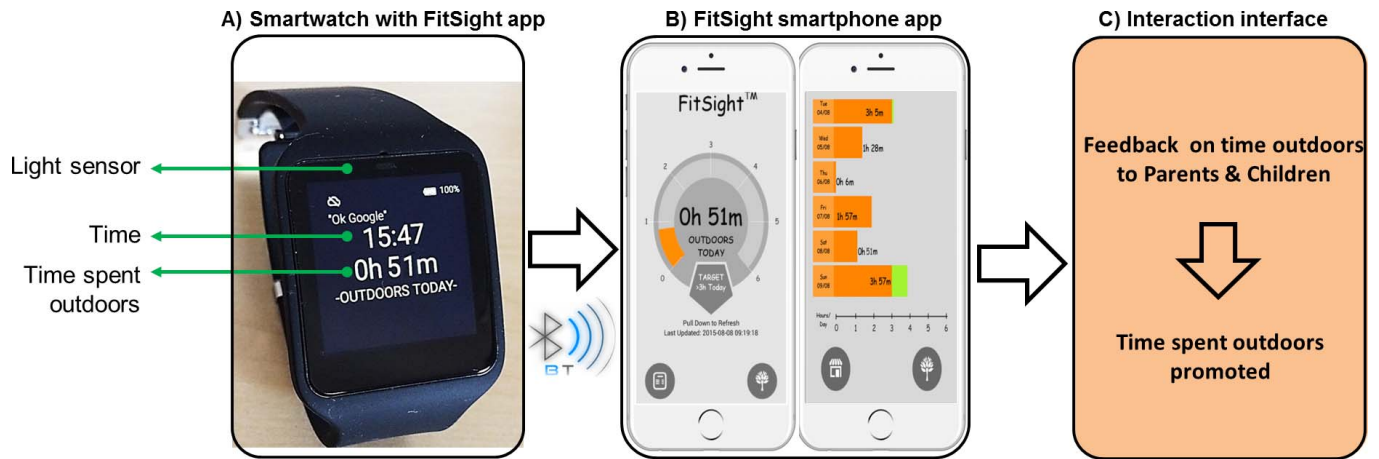


Figure 1. FitSight fitness tracker comprising (A) smartwatch, (B) companion FitSight app on smartphone showing home page, history page, and (C) interaction interface between child and parent.

additional 40-minutes class of daily outdoor activity compared with those in the control group ($N = 1903$, 30.4% vs. 39.5% ; $P < 0.001$).²¹ In Singapore, children spend only 30 minutes outdoors during a typical weekday (compared with 2 hours in Australia) and the rest of the time on “nearwork” related activities.²² Given the more indoor-centric lifestyle of children in urban Asian countries that is potentially acting as an active impediment to myopia prevention,^{22,23} increase in time outdoors may be effectively achieved through wearable health devices. For example, in the Singapore Family Incentive Trial (FIT) of 285 children, using a wearable pedometer motivated 77.8% of the children in the intervention group to achieve the goal of 8000 steps.²⁴ Likewise, there is a need for a sustainable, cost-effective and scalable wearable tool to quantify the amount of time spent outdoors as well as motivate the child to increase time spent outdoors. However, to date, no such tools combining solid scientific evidence and current technological advances in wearable strategies have been developed. A few recent studies have quantified time outdoors by using commercially available portable light sensors such as HOBO dosimeter or an Actigraph watch,^{25,26} but these have been merely used to record the light illuminance level and/or physical activity and are not designed to change behavior.

This study aimed to develop a novel wearable fitness tracker, comprising of a custom-made FitSight watch application (app) for a smartwatch and a companion smartphone app to encourage children to increase time outdoors. A second aim was to evaluate wear time pattern of FitSight tracker and the outdoor time pattern among children aged 6 to 12 years by estimating daily light illuminance levels.

Methods

The Development of the FitSight Fitness Tracker

Our team (coinventors: SSM, SHP, ZXQ) developed a FitSight fitness tracker (alpha prototype), a novel wearable gadget to record, quantify, indicate, and motivate wearers’ daytime outdoor activity. Details of this wearable gadget have been described in the relevant patent.²⁷ The FitSight fitness tracker consists of two components: (1) a commercially available smartwatch (Sony Smartwatch 3; Sony Corp., Minato, Tokyo, Japan) with custom-made FitSight watch app, and (2) a companion smartphone app running on a smartphone.

All the smartwatches were programmed to record ambient light illuminance levels of each child (i.e., illuminance [lux] at 1-minute intervals using custom-made FitSight watch app). This app enables the smartwatch to record the instant light illuminance levels the wearer is exposed to. As shown in Figure 1, it also calculates the amount of time spent outdoors by summarizing the accumulated time spent outdoors when the light illuminance level is above a predefined threshold.

A custom-developed companion software (both iOS and Android versions available) was installed in a smartphone so that outdoor time recorded by the FitSight watch app (daily and weekly summary) can be synchronized to the parents’ smartphone via Bluetooth communication. The main home page of the app displays the total time spent outdoors on the specific day as well as the daily target, thus

encouraging the child to be outdoors for more than 3 hours every day. The history page displays the time spent outdoors in all past days (Fig. 1B). To motivate children to increase time outdoors, a congratulatory message was displayed on the smartwatch and smartphone when the child achieved a daily set target of 3 hours of outdoor. And if the wearer's outdoor time was less than 3 hours at 12 PM or 3 PM, the message "Go and play outside!" and "Go outdoors this afternoon!", respectively, were displayed.

The accelerometer function of the smartwatch app was also enabled to record and monitor physical activity (steps) for every 30-minute epoch as "Yes" (i.e., one or more steps recorded during the epoch) or "No" (i.e., no steps recorded during the epoch) to draw inferences about smartwatch wear patterns. Daily "outdoor time" was defined as the amount of time spent outdoors during daylight hours (from 7 AM to 7 PM).

Twenty-three children aged 6 to 12 years with no medical conditions (that may limit outdoor activity) and parents who owned a smartphone were recruited through a nation-wide advertisement in Singapore. There were 10 boys and 13 girls with mean age of 9.2 ± 1.4 years including 19 Chinese and 4 non-Chinese. Of 23 children, 14 children participated in the study during school term and the remaining 9 during school holidays. All children were given the smartwatch to wear as well as myopia education brochures from the Health Promotion Board, Singapore. Parents of 14 of 23 children also completed a in-house feedback form, which included questions related to the FitSight tracker (with a 3-level rating scale: very poor, poor, good).

The study was conducted at the Singapore Eye Research Institute by following the tenets of the declaration of Helsinki. The study protocols were approved by the Human Research Ethics Committees of the National University of Singapore and the SingHealth centralized institutional review board. The nature of the study was explained to the children and their parent/s, and all parents provided written informed consent, while written assent was obtained from the children prior to participation.

Data Analysis

To determine the wear time pattern among children, number of nonwear days (i.e., days when the child did not wear the smartwatch for all 12 hours of daily "outdoor" time [from 7 AM to 7 PM]) were calculated based on the accelerometer's physical activity (steps) readings. The continuous regis-

tered movement for at least 1.5 hours during daytime (Yes, Yes, Yes recorded for 3 consecutive 30 minutes) were considered as time wearing a watch. Distinct trajectory groups of smartwatch wear time over the 1-week period were determined using latent-class growth analysis,²⁸ a type of growth mixture modelling, based on a zero-inflated Poisson model using the number of 30-minute epochs recorded as "Yes" on each day as the response or trajectory variable.

To evaluate the outdoor time pattern, the tracker-recorded daily light illuminance levels (lux) over 7 days of continuous wear for each child over the 12 hours (7 AM to 7 PM) of wearing the tracker were analyzed. Any recordings suggesting that the smartwatch had not been worn (no continuous movement for 1.5 hours during daytime based on the accelerometer's physical activity readings – i.e., No, No, No recorded for 3 consecutive 30 minutes) or that the light sensor had been covered (complete darkness during the day corresponding to 0 lux) were not included to calculate the mean light illuminance levels. The average daily light illuminance levels for each child were calculated for: (1) all days, (2) weekdays, and (3) weekends. The average amount of time spent outdoors with light illuminance levels above certain thresholds indicating outdoor locations during each day of smartwatch wear, was also calculated for each child for all days, weekdays, and weekends. Statistical analyses were performed using Stata Version 14.0 (Stata Corporation, College Station, TX) and IBM SPSS Statistics Version 21 (IBM SPSS Statistics, Armonk, NY), considering statistical significance at *P* less than 0.05.

Results

We developed the FitSight fitness tracker, a smartwatch-based wearable system to quantify and monitor the amount of time spent outdoors. It was found that the values of illuminance on the smartwatch were of the same order of magnitude as the in-house light-meter that was used as a reference. Of 14 parents who provided feedback on the FitSight tracker, 93% and 64% rated the FitSight fitness tracker and the smartwatch's wearability as good, and 7% and 36% rating it as poor or very poor. The overall performance of the FitSight smartwatch app and the FitSight smartphone app was rated as good by 50% and 64% of the parents, respectively.

Of 23 children, 61% wore the watch on all study days (0 nonwear days), while 26% had 1 nonwear day and 4.5% children each had 3, 4, and 5 nonwear days,

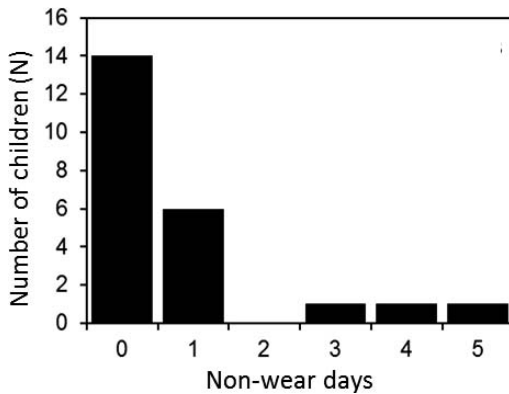


Figure 2. Distribution of nonwear days for 23 children based on accelerometer data.

respectively (Fig. 2). The number of nonwear days for the FitSight tracker was not significantly different between males and females ($P = 0.96$) and did not differ between age groups (7–8, 9–10, 11–12 years, $P = 0.09$). Two wear time trajectory groups were identified for the Fitness tracker using latent-class growth analysis, i.e., a ‘declining users’ group ($N = 7$; average trajectory indicating declining wear time over the 1-week period) and a ‘consistent users’ group ($N = 16$; average trajectory indicating consistent wear time over the 1-week period) (Fig. 3).

The average light illuminance levels and the amount of time spent outdoors by all children wearing the FitSight fitness tracker are shown in the Table. Mean and maximum daily light illuminance levels were 731 ± 501 lux and $31,669 \pm 32,415$ lux, respectively. Figure 4 depicts the variations in light illuminance patterns for two children on a typical weekday and weekend day. For both children, there were fewer outdoor spurts with light levels greater than 1000 lux on a weekday, with most of the time being spent indoors (light levels < 1000 lux). On a weekend day, although there were relatively more spurts in both children compared with weekday, a similar trend was observed with the number of spurts and its duration.

Overall, children on average spent about 65 minutes in light levels greater than 1000 lux with 1 hour on weekdays and 1.3 hours over the weekends (60 ± 46 vs. 79 ± 53 minutes, $P = 0.19$). Number of spurts of outdoor time (light illuminance level > 1000 lux) in all children was 8 ± 3 spurts (Fig. 5) with the mean duration of 34 ± 32 minutes (Fig. 6). Of the total 23 children, 78% had at least 5 spurts of light illuminance level greater than 1000 lux, and for 65% the maximum spurt duration was less than 30

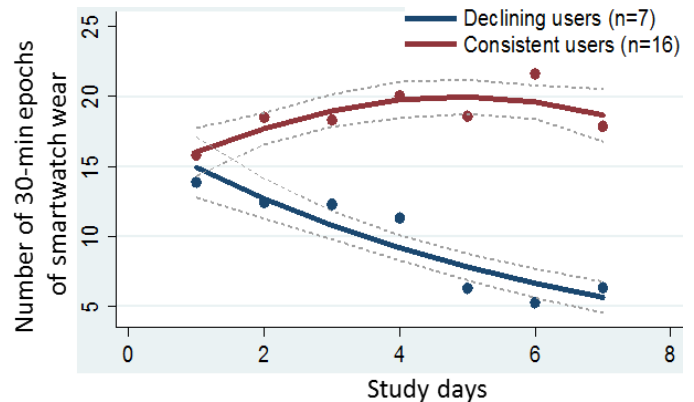


Figure 3. Smartwatch wear trajectory groups identified using latent class growth analysis. Dotted lines indicate 95% confidence interval limits of the estimates.

minutes. The time at which maximum light illuminance occurred varied across the children, with the spurts mostly seen during the periods 9 AM to 10:30 PM, 12 PM to 1 PM, or 3 PM to 4 PM. Children spent significantly less amount of time at light illuminance levels greater than 5000 lux (on weekdays: 14 ± 17 minutes and weekends: 25 ± 35 minutes) compared with light illuminance levels greater than 1000 lux ($P < 0.001$).

Discussion

A noninvasive, wearable, smartwatch-based fitness tracker, FitSight, has been developed to promote daytime outdoor activity among children by setting a daily target for time outdoors. The FitSight fitness tracker is novel in both design and principle with custom-made FitSight watch app to log the instant light illuminance levels the wearer is exposed to, and a companion smartphone app to synchronize the time outdoors recorded by the smartwatch onto the smartphone. We believe that this FitSight fitness tracker system is first of its kind and further studies will be conducted to evaluate whether the tracker can encourage children to spend more time outdoors and prevent myopia. A good smartwatch wear rate in 61% of children and constant use of the watch during 7 days by 69% of children indicate that there could be minimal barriers to usage of this fitness tracker due to user-friendly design, hassle-free synchronization via Bluetooth, and a quick launch app in a smartphone.

The mean light illuminance level recorded by the FitSight watch daily and the time spent outdoors with a light illuminance level greater than 1000 lux found in the current study were lower (40%) than those

Table. Light Illuminance Levels among Children Who Wore the FitSight Fitness Tracker over 7 Continuous Days

	All Children (N = 23)			P Value
	All Days	Weekdays	Weekends	
Mean (SD) daily light illuminance level, lux	731 (501)	621 (620)	1,005 (1,031)	0.16
Mean (SD) maximum daily light illuminance level, lux	31,669 (32,415)	28,654 (43,865)	39,206 (39,780)	0.42
Daily bright light illuminance, min				
Mean (SD) light illuminance level > 1000 lux per day, min	65 (37)	60 (46)	79 (53)	0.19
Mean (SD) illuminance level > 2000 lux per day, min	39 (23)	34 (28)	51 (42)	0.15
Mean (SD) illuminance level > 3000 lux per day, min	29 (18)	25 (23)	38 (36)	0.20
Mean (SD) illuminance level > 5000 lux per day, min	17 (14)	14 (17)	25 (35)	0.21

SD, standard deviation.

recorded among children living in Australia as reported by Read et al.²⁶ although the studies cannot be directly compared due to differences in methodology. These results are consistent with the findings of a previous study showing that the children in Singapore

spent only 30 minutes outdoors during a typical weekday compared with 2 hours by children in Australia, and that they spent the rest of the time on watching television, using the computer, reading or writing, and so on.²²

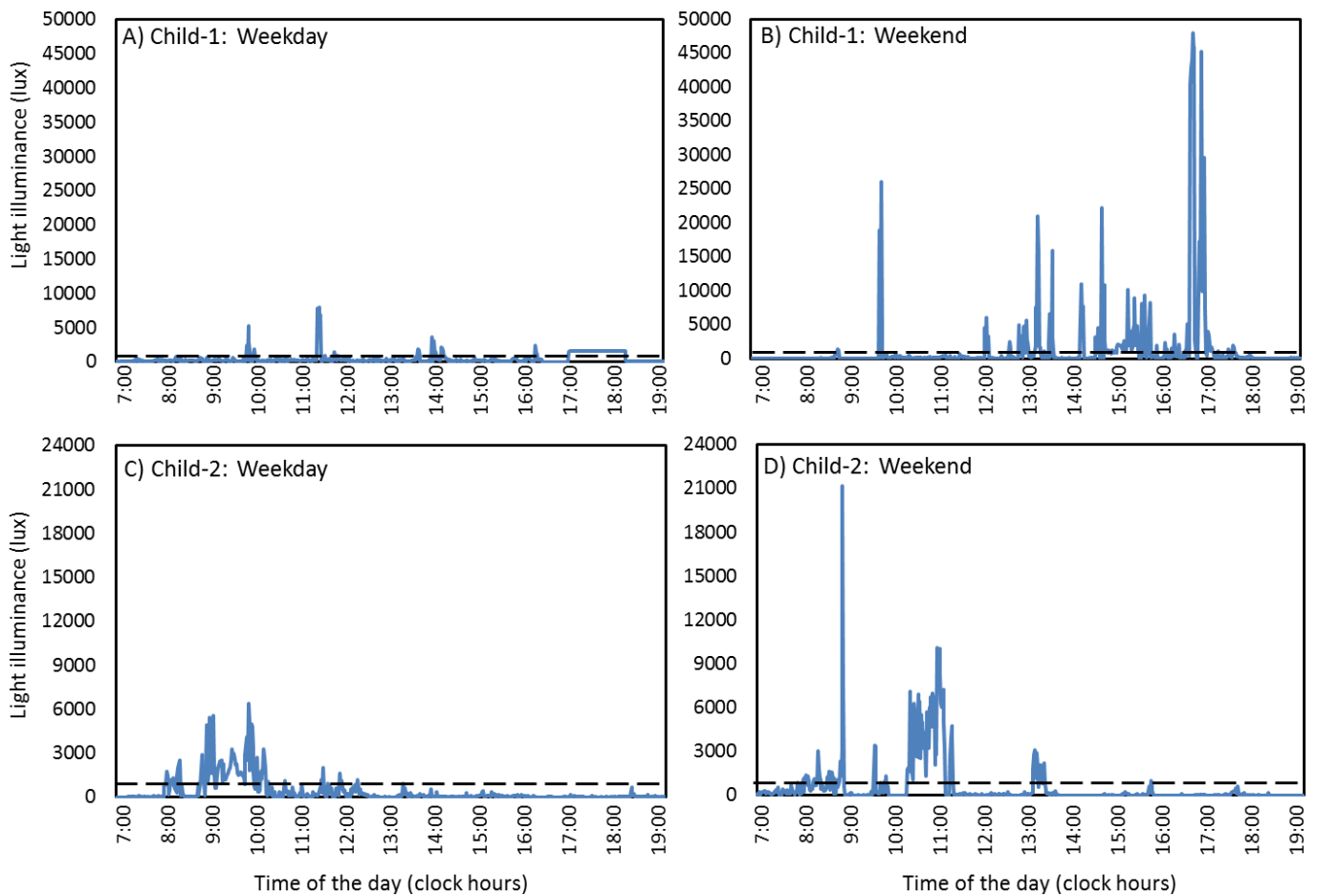


Figure 4. Light illuminance levels experienced by child 1 (A, B) and child 2 (C, D) on a typical weekday and weekend day. Dashed lines represent light illuminance levels > 1000 lux.

Table. Extended

	School Term (N = 14)	School Holidays (N = 9)	
	All Days	All Days	P Value
Mean (SD) daily light illuminance level, lux	678 (446)	812 (596)	0.55
Mean (SD) maximum daily light illuminance level, lux	36,009 (36,400)	34,918 (25,536)	0.44
Daily bright light illuminance, min			
Mean (SD) light illuminance level > 1000 lux per day, min	62 (38)	71 (37)	0.57
Mean (SD) illuminance level > 2000 lux per day, min	36 (24)	44 (23)	0.38
Mean (SD) illuminance level > 3000 lux per day, min	25 (16)	35 (20)	0.19
Mean (SD) illuminance level > 5000 lux per day, min	14 (11)	22 (17)	0.17

The number of spurts for bright light illuminance has not been investigated in detail previously. The spurts may denote pockets of outdoor activity. We found that 78% of the children in this study had at least five spurts of light illuminance level greater than 1000 lux with a wide range of maximum spurt duration (mean duration of 34 minutes). A few children had relatively more spurts, but with shorter spurt duration, while in other children it was the other way. The finding of fewer spurts with light levels greater than 1000 lux on weekdays, suggest that children spend much less time outdoors on a school day. The time periods during which most of these spurts occurred (9 AM to 10:30 AM, 12 PM to 1 PM, or 3 PM to 4 PM) indicate that the outdoor patterns observed in this study are possibly related to the break time in the school or the child’s travel time to their school and home in morning and evening, respectively. Time outdoors could be further increased if

additional school or after school programs are available. Because children already spend relatively more time outdoors on weekends, organizing community-based outdoors programs on weekdays may be beneficial.

With advances in technology, wearable fitness trackers with sensors are being widely used and well accepted by individuals seeking to enhance their personal fitness. Wearable gadgets such as Fitbit, JawboneUP, and so on are being used to measure movements through accelerometers, often using a typical target of 10,000 steps per day.²⁹ Given the more indoor-centric lifestyle of children in urban Asian countries, this fitness tracker that motivates them to spend time outdoors to achieve a daily target could be beneficial in addressing the epidemic of myopia. Because modification of the academic curriculum is difficult, and at the same time outdoor classes or glass-built classrooms may be costly and difficult to implement, children

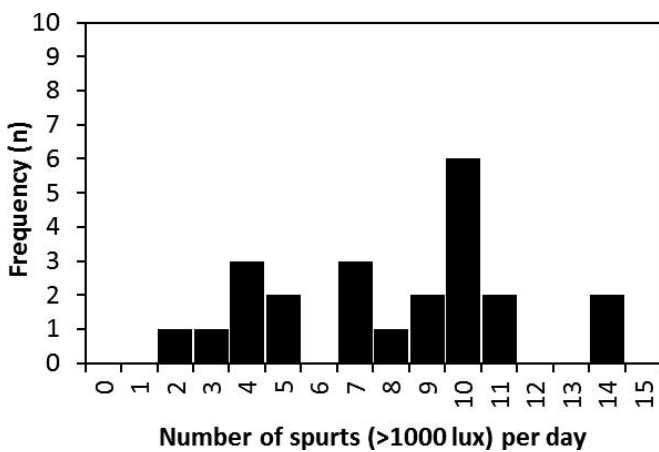


Figure 5. Distribution of children with spurts of light illuminance level >1000 lux.

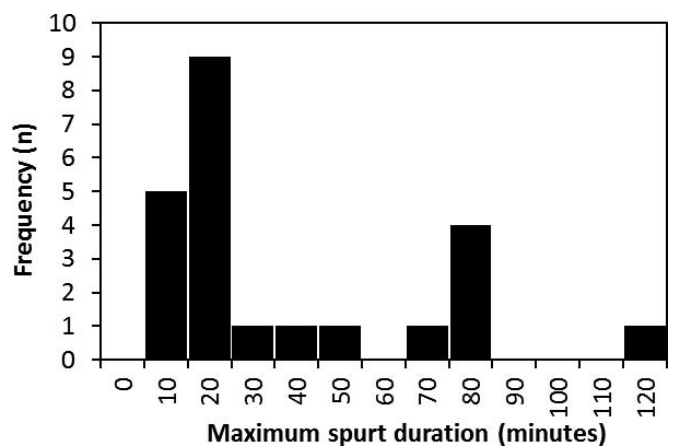


Figure 6. Duration of maximum spurt, for all 23 children on a selected weekday.

should be encouraged to spend time outdoors after school hours and on weekends. Reminder notifications every day to increase time outdoors and congratulatory message on accomplishing the set target to encourage them are special features of the FitSight tracker to keep children motivated to go outdoors. The FitSight fitness tracker type of feedback system and support by involvement of parents, could encourage children to spend more time outdoors. For parents with children who have a particularly high risk of developing myopia, use of such a gadget could increase their children's time outdoors that may reduce the incidence of myopia.

The strength of our study includes the novelty of the FitSight fitness tracker. The tracker also tracks steps, and may therefore improve children's overall health in addition to myopia prevention. Another unique feature of this tracker is that it is designed to be worn by children in contrast to most other pedometers designed primarily for adults. This Fitness tracker also provides crucial real-time information about light exposure levels, which may be of interest to researchers investigating the effect of light on myopia development. The main limitation of the study is the small sample size and the lack of sufficient power to determine small differences. This was a pilot feasibility study and the results of wear pattern and outdoor pattern were assessed only for a period of 7 continuous days. We did not evaluate the effect of the FitSight tracker on change in outdoor behavior among children, but future randomized controlled trials with a large sample size and a comparison group of children who do not wear the tracker will be conducted to determine FitSight tracker's ability to encourage children to increase time outdoors. We are also developing a stand-alone FitSight watch prototype and further studies will be conducted to test the tracker thoroughly in a large sample.

To conclude, the novel FitSight fitness outdoor tracker has been developed and a majority of children used it on all study days indicating acceptance of this user-friendly wearable system. The time spent outdoors by children in this study was less than a daily set target of 3 hours of outdoor suggests the need for encouragement to increase time outdoors to prevent myopia. This wearable fitness tracker designed to change outdoor behavior in children may complement outdoor programs organized at both school and at the community level,^{23,30} to increase the time spent outdoors.

Acknowledgments

The authors thank DingSun, Veronica, and Wenfei for their contributions in data collection and statistical analyses.

Disclosure: **P.K. Verkicharla**, None; **D. Ramamurthy**, None; **Q.D. Nguyen**, None; **X. Zhang**, None; **S.-H. Pu**, None; **R. Malhotra**, None; **T. Ostbye**, None; **E.L. Lamoureux**, None; **S.-M. Saw**, None

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