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Objective measurement of spectacle wear with a temperature sensor data logger

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Abstract

Purpose—This study seeks to establish the utility of the SmartButton Data Logger (www.acrsystems.com) to monitor spectacle wear for research and clinical applications.

Methods—Fifty adults wore a thermosensor on their spectacles for two weeks for each of two mount types while keeping wear-time logs. Temperatures during reported spectacle wear (ON) were compared to temperatures during non-wear (OFF) with repeated measures analysis of variance (ANOVA). In addition, two strategies to approximate spectacle wear from temperature data were evaluated: 1. Filtering data based on temperature ranges to identify spectacle wear (either group mean ON temperature, or an individual's mean ON temperature), and 2. Separate examiners inspecting temperature against time plots to identify spectacle wear. The success of these methods to approximate wear time was evaluated by per cent error with respect to subject reported wear time.

Results—Group mean ON (31.8 [0.6] Celsius °C) and OFF (24.7 [1.5] °C) temperatures differed significantly ($F_{1,47}=471.2$, $p<0.001$), but there was no difference in temperature between mounts ($F_{1,47}=1.9$, $p=0.18$). Median per cent error and first and third quartiles (Q1, Q3) of each technique used to approximate wear time were: group mean filtering = 8% (Q1 3%, Q3 18%), individual mean filtering = 7% (Q1 4%, Q3 19%), Examiner 1 = 6% (Q1 2%, Q3 14%), Examiner 2 = 7% (Q1 3%, Q3 12%).

Conclusions—The SmartButton can monitor spectacle compliance in patients with all approximation methods evaluated providing less than 10% median per cent error in wear time.

Keywords

spectacle compliance; dose monitoring; thermosensor; amblyopia; objective monitoring

Introduction

Assessing spectacle compliance is an important factor in the management of some patients, as well as for the evaluation of treatment success for various ocular conditions. For example,

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spectacle wear alone has been shown to improve visual acuity in patients with strabismic or combined strabismic and anisometropic amblyopia,¹ and thus spectacle non-compliance could negatively impact treatment success. Measuring spectacle wear compliance may also be useful to reveal predictive factors as to why children choose not to wear their spectacles.²⁻⁴ Currently there is not an accepted best method to objectively quantify spectacle wear time for patient care or research. Investigators may utilise questionnaires administered to subjects or parents of subjects to quantify wear time; however, this methodology has limitations in that it has been shown that adult subjects overestimate spectacle wear time significantly on questionnaires.^{3,5,6} Another strategy is to evaluate compliance based on whether subjects wear their spectacles to follow-up appointments, but this too is not a precise measure of day to day compliance.^{7,8} Utilising smartphone technology, such as through texting reminders to individuals to report whether they are currently wearing spectacles, or utilising diary applications on smartphones for subjects to report wear time may improve compliance over paper questionnaires; however, these methods still rely on the individual's commitment to track wear, making an objective technique that eliminates the responsibility of the individual appealing.

A thermosensor is a device that autonomously records temperature data from the surrounding environment at set intervals. Multiple researchers have sought to use a thermosensor to objectively measure spectacle or eye patch wear time (occlusion dose monitoring).^{5,9-11} One recent study utilising objective spectacle monitoring in children was reported by Maconachie *et al.*¹¹ who used a dose monitoring system, previously validated for ocular occlusion monitoring, mounted on spectacles to monitor spectacle wear. This system was worn by 40 children undergoing treatment for amblyopia and had a reported success rate of 83% to collect compliance data. Although successful in the majority of subjects, the device is relatively large and cosmetically unappealing, and 17% of sensors did not successfully collect data. An alternative device reported in the literature is an orthodontic thermosensor, TheraMon[®] microsensor, (www.thera-mon.com) which can be mounted discretely to the temple of spectacles; however, this device was reported to have difficulty discerning spectacle wear in environmental conditions of 33 to 37° Celsius (C), and is also not available for purchase outside of Europe.⁹

The overall goal of this work is to address the previous limitations of objective spectacle wear monitoring systems by evaluating the ability of a smallprofile, widely available, commercially developed temperature sensor to accurately monitor spectacle wear in a large sample of subjects in a variety of climates. Specifically for this study, we report data for a hot summer climate when using two different mounting strategies of the thermosensor to subjects' spectacles. In addition we report two strategies to approximate spectacle wear from temperature data: filtering data based on temperature ranges to identify spectacle wear versus examiner inspection of temperature against time plots to identify spectacle wear. We aimed to recruit a large sample of adult subjects in an effort to collect data obtained during a variety of wear patterns and indoor versus outdoor environments to help determine conditions that could potentially negatively impact accurate assessment of spectacle wear time. These findings have resulted in recommendations regarding deployment of the device to monitor spectacle wear for use in future research studies.

Methods

Subjects

This research was approved by the University of Houston Committee for the Protection of Human Subjects and has been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was collected from all subjects. Adult participants (18 years or older) were recruited from the students, faculty, and staff at the University of Houston College of Optometry, as well as adults from the community who were family, friends, or acquaintances of the investigator conducting data collection. All subjects were required to own spectacles and commit to part-time wear for a minimum of 10 hours per week throughout the duration of the study. Full-time wear was discouraged due to the desire to eliminate predictable wear patterns from the dataset, and thus potential participants who were dependent upon full-time spectacle wear (e.g. did not have contact lens corrections or secondary spectacles as an alternative refractive correction option) were not included.

Description of thermosensor device

The thermosensor used for this study was the SmartButton Data Logger Temperature Recorder (www.acrsystems.com). The sensor is a commercially available, low voltage, battery powered Class B digital device that passively obtains and stores temperature readings at fixed time intervals (1 to 255 minutes). Advertised applications of the device by the manufacturer include perishable shipment and storage temperature monitoring. The sensor specifications are as follows: 17.35 mm diameter $\times$ 5.89 mm height; 4 grams; 3.0 volt lithium battery (approximated battery life of 10 years at a 20 minute sample rate); temperature operating range -40°C to 85°C ; and logs up to 2048 consecutive time-stamped temperature measurements in internal memory in 0.5° increments. The internal memory is retrieved through a USB interface connected to a computer with TrendReader for SmartButton Software (www.acrsystems.com); data are not transmitted wirelessly from the device. The software extracts the data into a spreadsheet with temperature recordings and the corresponding time-stamp, as well as a graph of temperature versus time. Calibration of the device is not necessary, but the agreement of the sensors was assessed prior to executing the study by setting 25 sensors to sample temperature in the lab for a 17 hour period. All sensors recorded temperatures within 0.5°C of the mean recorded temperature over the duration of time sampled and were thus considered to have good agreement.

Mounting strategies

Temperature sensors were mounted to subjects' spectacles in two different ways in an attempt to obtain measurements of the skin's temperature when spectacles were being worn. While contact with the skin was achieved in subjects with short hairstyles, close proximity was also adequate to sample the heat emitted by the subject's head and ear. One mount type used a commercially available double-sided adhesive circle, 15 mm in diameter, to adhere the sensor directly to the temple of the subject's spectacles behind their ear (Figure 1A). The alternate mount type was a custom designed silicone sleeve which held the sensor either above or below the temple of the spectacle frame behind the subject's ear (Figure 1B). Only one subject wore the silicone mount below the temple due to spectacles with straight temples

that accommodated this option. The silicone sleeves were produced at the University of Houston College of Optometry, using custom moulds designed and manufactured by the technical services branch of the College, UHCO Technical Services. Each mount type was worn for two weeks by every subject with mount type order randomised.

Data collection

Subjects were requested to wear their spectacles with the sensor for a minimum of 10 hours per week and to complete daily logs (accounting for all 168 hours of the week) with specific times (hour and minute) that spectacle ON/OFF transitions occurred. These logs were returned to study investigators weekly. Subjects were encouraged to document additional details in the logs which may impact temperature readings, such as whether or not the subject's hair covered the sensor during wear and other environmental details corresponding to the location of the glasses during specific log times (e.g. wearing glasses while driving, activities indoors, activities outdoors, leaving the glasses in a parked car, etc.). Subjects were informed that the study goal was to validate the use of the sensor for monitoring spectacle wear and were thus encouraged to use note-taking programs on their mobile device to assist in the documentation of exact times that they put their spectacles on or off, and to transfer this information daily to the log sheets. An example log (Table 1) was provided to subjects at the beginning of the study.

Sensors were set to record time-stamped temperatures every five minutes for one week (seven days and two hours). At the end of each week, subjects returned to the lab for a follow-up visit. At each follow-up visit, subjects submitted their log from the previous week, data from the sensor was downloaded and the sensor was reset. At the end of each two week period, subjects completed a survey about the mount type worn for the past two weeks. The survey was scored 1-5 (1=worst, 5=best). Subjects were asked to rate the comfort of the mount, the cosmetic acceptability of the mount, and the perceived fragility of the mount (5=not fragile). The survey also included a question asking whether the subject would be willing to continue wearing this type of mount, which was answered YES or NO.

Data Analysis

Subject log confidence

Subject log data were manually entered into the downloaded, time-stamped temperature data using Microsoft Excel to create a file of subject reported spectacle ON/OFF times associated with temperature readings. Subject logs were graded for confidence (high, medium, low) in the accuracy of logged data. The confidence grading was standardised as follows: characteristics of high confidence logs included the subject accounted for all of the time in the week; time markings were specific and clear (e.g. AM/PM); and environmental details were provided. Medium confidence meant one of the characteristics of high confidence was missing consistently throughout the log. Low confidence meant that two or more of the characteristics of high confidence were missing throughout the log, or subjects reported poor log quality and/or filled in their logs at the time of the follow-up visit.

Establishing a reference to compare temperature data

The temperatures recorded by the SmartButton Data Logger during times when the subject reported that the spectacles were on served as truth for temperature data in this experiment. Mean and standard deviation (SD) of the temperatures recorded during the time intervals the subject reported the spectacles ON versus OFF were calculated for each subject individually and for the entire group. These temperature ranges were then used to filter individual subject data to predict wear times as described below.

Approximating spectacle wear by temperature filtering

First, the ability to approximate spectacle wear was tested based purely upon the temperatures recorded by the thermosensor. Multiple methods of data filtering were attempted with the goal of determining an appropriate temperature range to capture ON temperatures without overlapping the OFF temperatures. The top two performing methods are reported here. The first defined spectacle ON time as temperatures falling within the entire group mean and 1.5 SD of ON temperatures for Week 1 data, which ultimately included temperatures from 28.4 to 35.2 °C. The other method was individualised per subject and defined spectacle ON time as temperatures falling within 1.5 SD of each individual subject's mean spectacle ON temperature. Using these two filtering methods, spectacle wear was approximated across each week of study participation and compared to subject reported spectacle wear times.

Approximating spectacle wear by examiner inspection of temperature plots

Second, in an attempt to utilise information from the patterns of the temperature versus time plots rather than merely the actual temperature values themselves, spectacle ON time was approximated by two examiners visually inspecting the log data who were masked to the subject logs. Each examiner independently viewed temperature versus time plots using Temperature Log Viewer 1.2, novel software (Core Programming Module, University of Houston College of Optometry) developed in MATLAB (www.mathworks.com) for this study to allow examiners to mark presumed spectacle ON and OFF times on the plots of the raw temperature data (Figure 2). The examiners reported that they determined what was believed to be spectacle ON time based on sharp increases/decreases in temperature, temperature range, and the frequency (noise) of the data trace. The software then calculated total spectacle ON time based on examiner markings and compared this to subject reported ON time.

Accuracy of approximation methods

Per cent error was calculated to determine the accuracy of each method of spectacle wear time approximation for all 50 subjects for Week 1 data using the formula shown here (Equation 1).

$$\text{Percent Error} = \left(\frac{\text{Approximated ON Time} - \text{Subject Reported ON Time}}{\text{Subject Reported ON Time}} \right) \times 100$$

Equation 1

The absolute value of per cent error was grouped into three categories (10%, >10 to 20%, and >20%) for each wear approximation method and chi-square analysis performed to determine whether the distribution of errors differed between methods.

Survey data analysis

Mean and SD were calculated for the first three survey questions and paired t-tests used to compare the adhesive mount type to the silicone mount type. Yes/No responses to the last survey question for both mount types were tallied.

Wear pattern and environmental condition assessment

A subset of data from subjects with high quality logs for all four weeks was further descriptively analysed to identify potential sources of high per cent error with the various wear time approximation methods. Both subject wear patterns (total wear time, number of ON/OFF transitions, average duration of continuous wear time) and environmental details were compared across subjects in an effort to determine sources of poor spectacle wear time approximation.

Analysis of sampling interval

An additional aim of this study was to identify the minimum sampling rate necessary to approximate spectacle wear time, given that sampling rate will impact total storage time, and therefore the need to visit the laboratory to download data. The sensor in this study was set for a high density sampling rate (every five minutes) which yielded seven days of data. To determine whether a coarser sampling rate would negatively impact per cent error, the functionality of the plot marking software was updated (Temperature Log Viewer 2.0) which allowed the examiner to select the sampling rate for which to view the temperature versus time data, allowing coarser representation of the original set of temperature versus time data. Examiner 1 re-graded the plots for Week 1 for eight subjects with high confidence logs, using three additional sampling intervals (every 20 minutes, 30 minutes, and 60 minutes). Sampling at these intervals would allow the device to be deployed for the following periods of time: 5 minute sampling = 1 week; 20 minute = 4 weeks; 30 minute = 6 weeks; and 60 minute = 12 weeks. Per cent error for each sampling interval was compared to evaluate the impact of coarser temperature sampling.

Results

Fifty-three subjects were enrolled in the study, three of whom withdrew prior to the conclusion of the study. Two subjects withdrew due to inability to schedule weekly follow-

up appointments and the other due to skin irritation from the silicone mount against his bald head. One subject lost a sensor due to the adhesive mount detaching from the spectacle frame, but a new sensor was dispensed and the subject completed an additional week of data collection. In total, 50 subjects (32 female, 18 male) completed data collection of 10 or more hours of weekly wear and are included in the analysis below. Data were collected between May and August in Houston, Texas. The outdoor temperature range during this period was 22 to 37°C (73 to 103° Fahrenheit [F]).

Log confidence for all 50 subjects in Week 1 was as follows: 18 high, 28 medium, and 4 low. Log confidence varied within most subjects over the four week study period, and generally decreased. The number of logs with high confidence across weeks 1 to 4 were 18, 15, 12, and 17, respectively. Therefore, we present the Week 1 data for all 50 subjects when log confidence was highest, but included only the eight subjects with high log confidence for all four weeks of data collection for the subsequent analysis.

Temperatures extracted from data sensors were categorized as spectacles ON or OFF based on merging data logger time stamps with subject log reported wear activities. Group mean ON and OFF temperatures for all subjects for Week 1 are shown in Table 2. Data were analysed by repeated measures ANOVA with two between group factors (gender, mount types). Group mean ON (31.8 [0.6] °C) and OFF (24.7 [1.5] °C) temperatures differed significantly ($F_{1,47}=471.2$, $p<0.001$), as did male and female mean temperatures, with females averaging 1°C higher than males ($F_{1,47}=4.6$, $p=0.04$). There was not a significant difference in mean temperatures between mount types ($F_{1,47}=1.9$, $p=0.18$).

Accuracy of approximation methods

The distribution of the absolute value of per cent error from Week 1 for each wear approximation method is shown in Table 3. All methods had a similar distribution of per cent error for the 50 subjects across the three categories (χ^2 (6, $N=200$) = 3.7, $p=0.72$) and there was no significant difference in median per cent error across methods (Kruskal-Wallis Test, $df=3$, $H=1.73$, $p=0.63$).

Although the distribution of per cent error did not differ between methods (Table 3), the overall magnitude of error for those subjects falling outside of $\pm 20\%$ error was much greater for the filtering methods. Per cent error by examiner approximation was less than 100% for all but one subject whose error neared 200%, whereas the filtering techniques had five instances of per cent error exceeding 100%, one of which exceeded 800% error. For all methods, the largest errors were positive errors, indicating an overestimation of wear time (range for all subjects, all methods = -27% to 822%).

Survey results

Subjects did not have a preference in terms of comfort with a mean survey score of 3.9 [1.2] for the adhesive mount and 3.5 [1.2] for the silicone ($t_{1,49}=1.45$, $p=0.15$). However, subjects preferred the cosmesis of the adhesive mount (3.9 [1.1] versus 3.3 [1.1]; $t_{1,49}=3.35$, $p=0.001$) and perceived the silicone mount as less fragile (4.7 [0.6] versus 3.8 [1.0]; $t_{1,49}=-5.09$, $p<0.001$). As to whether or not they would wear the mount type again, 42/50

subjects reported YES for the adhesive mount, while 39/50 reported YES for the silicone mount.

Subgroup results

Data from the eight subjects with high quality logs for all four weeks were further analysed to identify potential sources of high per cent error with the various approximation methods. Table 4 presents a summary of signed per cent error, by both examiner approximation and temperature filtering, for these subjects for all weeks. Both the filtering methods and examiner approximation performed well with all techniques having less than 20% absolute error for a majority of the subjects across the four weeks of spectacle wear. However, as was noted previously with the Week 1 data, the magnitude of error was often much higher for the filtering methods for those instances where per cent error exceeded 20%. It can be seen in Table 4 that Subject 9 accounted for the majority of the higher magnitude error for all methods. When looking only at the examiner approximation, Subject 9 and Subject 19 accounted for all of the instances of error greater than 20%.

Wear pattern and environmental condition results

Subject spectacle wear patterns and environmental conditions were next inspected to identify possible sources for poor approximation of wear time for Subject 9 and Subject 19. As can be seen in Figure 3, both subjects had similar wear patterns that differed from the group as a whole to include lowest total amount of wear time (Figure 3A), highest number of ON and OFF transitions (Figure 3B), and lowest durations of continuous spectacle wear (Figure 3C).

When evaluating the environmental details provided by each of the eight subjects on their written logs, there was a mix of indoor and outdoor activity throughout the study, with most of the data consisting of indoor wear and indoor storage of spectacles. However Subject 9, who had the worst error in wear time approximation, primarily stored their spectacles in the car, only wearing their spectacles for short duration driving trips. In particular, the storage of the spectacles in an unshaded parked car overnight allowed the sensor to reach temperatures that mimicked body temperature, posing difficulty for both the examiner and filtering techniques. An example of one week of temperature data from Subject 9 is shown in Figure 4, the pattern of which is in stark contrast to the subject in Figure 2 who primarily kept their spectacles indoors.

Three of the eight subjects also reported storing their spectacles in a pocket or hanging them on their shirt throughout the study, a behaviour that was suspected to mimic ON spectacle temperatures. However, this behaviour was not associated with higher per cent error. Upon inspecting the temperature data during these periods of pocket or shirt storage, a sharp decrease in temperature was observed when transferring spectacles from ON to a pocket or shirt. The average pocket/shirt temperature was several degrees lower (28.2 [3.5] °C) than the average ON temperature (31.8 [0.6] °C) for these subjects.

Sampling interval results

Table 5 shows that per cent error did not vary dramatically when decreasing the sampling rate. The 30 minute sampling interval was the only interval with all eight subjects having

less than 20 per cent error with small increases in per cent error for some subjects, but a sizeable improvement in per cent error for Subject 9.

Discussion

The results of this study indicate that the SmartButton Data Logger Temperature Recorder is successful as a tool to monitor spectacle wear time utilising the following recommendations. Spectacle wear time approximations were most accurate for the method of examiners marking temperature versus time plots for each subject's data, as evidenced by the smaller overall range of per cent error. Although this study initially used a five minute temperature sampling rate, utilising a coarser temperature sampling rate of 30 minutes is likely to be successful when utilising examiner manual markings of temperature versus time plots and will extend subject follow-up time. We recommend that examiners collecting data in warm climates similar to our study location (22 to 37 °C) advise subjects not to leave their spectacles in a car, as this could lead to a higher chance of temperature patterns that mimic true spectacle wear. Lastly, regarding our two tested mount strategies, we have adopted a preference for the silicone mount type, largely due to the increased risk of losing both the sensor and data if adhesive mounting fails.

Although the data lead us to favour the examiner marking method for wear time approximations, temperature filtering methods were generally robust. Utilising the filtering methods may be appealing in that software to plot and mark temperature versus time would not be required, and the speed to analyse findings would be improved. However, some consideration of what range of temperatures to use for classification of spectacle wear is required and could vary by individual or climate. For example, our data found warmer mean ON temperatures for female subjects (Table 2) which we predict is related to hairstyles covering the sensor during spectacle wear. The individual temperature filtering method eliminates complications from these inter-subject ON temperature variations; however, to utilise this method, examiners would need to pre-collect temperature data by requiring subjects to wear their spectacles with the sensor for a known time interval in order to calculate that individual's mean ON temperature. In this study, the group mean filtering method had similar median per cent error as the individual mean filtering method (Table 3 and Table 4), suggesting that the effort to obtain individual filtering ranges may not yield a meaningful improvement in accuracy. The group mean temperatures used for temperature filtering in this study (28.6 to 35.5 °C) can likely be utilised by investigators deploying the device in similar environmental climates and would avoid the need to pre-collect temperature data to define a filtering range; however, further studies are needed to evaluate the data logger's performance in colder climates to determine if the outdoor temperature affects recorded ON temperatures and the recommended filtering ranges.

It is important to consider the level of accuracy when utilising an objective technique, such as a temperature sensor to monitor spectacle wear. It is expected that most investigators desiring to monitor spectacle wear will prescribe full-time wear, and thus we are most interested in whether or not the sensor can be used to determine if a subject wore their spectacles for the majority of the day. In this study, we evaluated the success of the data logger to monitor spectacle wear by per cent error and viewed less than 20% error (at least

80% accuracy) as a reasonable threshold for success. Assuming full-time wear is 16 hours per day, a device with 80% accuracy would indicate that the subject wore their spectacles between 12.8 and 19.2 hours. Although this range is large, either end indicates that the subject wore their spectacles for the large majority of the day, indicating good compliance with spectacle wear. We can also consider the subject that did not wear spectacles at all for a given day. If the device overestimated and revealed the subject wore their glasses approximately three hours that day (a number derived from the level of overestimation observed with a 20% overestimation error on a full-time wearer), we would know this is overall poor compliance. Ideally, this device would perform without overestimation, a complication that can be minimised by avoiding environmental spectacle storage situations in which the spectacles reach body temperature.

The results of this study show similarities to that of Januschowski *et al.*⁹ and Maconachie *et al.*¹¹, in that all three sensors provided an accurate, safe, and relatively comfortable means of approximating spectacle wear time. However, the SmartButton data logger may be preferred given that it is widely available, did not incur difficulties discerning spectacle wear for warm environmental conditions (with the exception of parked cars), and had good cosmetic acceptability.

One limitation in our study is the fact that there is potential for an inherent error in matching subject logs and temperature plots due to the fixed sampling rate of the thermosensor. The thermosensor only provided data every five minutes, but subjects were asked to report wear times to the minute and thus when merging the subject logs with the temperature data, there were many instances where subject reported times did not precisely match the time stamps of the temperature data. Data were reconciled to each other with the rule that a reported ON transition that fell outside of a five- minute interval would be listed at the next closest time. For example, if the thermosensor recorded data points at 6:30 and 6:35, but the subject reported an ON transition at 6:33, the spectacles would be marked OFF for 6:30 and ON for 6:35, leading to an error of two minutes. Given the relatively small number of spectacle ON/OFF transitions over the course of a week of subject wear and the minimum required wear time of 10 hours, these small errors should not significantly impact the overall findings of the study.

A second limitation in our study is that all participants were adults. Given that spectacle compliance may be of particular interest in paediatric populations, further studies may be needed to evaluate whether the device performs similarly and is well-tolerated in children. While smaller frame designs should not impair the ability to mount the device to children's spectacles using the mounts described in this study, the cosmetic appearance may not be as subtle if children have smaller ears that do not hide the sensor well, particularly for those with short hairstyles.

Lastly, in adopting the use of a data logger to monitor spectacle wear, one must consider that the presence of such a monitor may alter the wearer's behaviour. In the present study, subjects were instructed not to adhere to predictable wear patterns, so as to provide a more diverse sampling of wear patterns for evaluation of the device. However, in cases where the goal is to have individuals wear spectacles full time, it is possible that the presence of the

data logger will encourage compliance while it is worn, but that wear patterns could change once monitoring is discontinued.

Conclusions

The SmartButton Data Logger is a promising device to monitor spectacle compliance in patients. The device was well-tolerated by adult subjects for a four week period, and provided approximations of spectacle wear time with median per cent error of less than 10% and overall error falling within 20% for the large majority of subjects.

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Figure 1.

A Double sided adhesive circle to adhere the sensor to the temple of the spectacle frame behind the subject's ear. **B** Custom designed silicone sleeve which held the sensor either above (shown here) or below the temple of the spectacle frame behind the subject's ear.

Figure 2. A sample of a completed plot using Temperature Log Viewer 1.2. During evaluation of the plot, examiners can only view the solid black line depicting temperature versus time. The green (ON) and red (OFF) dashed lines indicate the manual markings placed by the examiner to approximate transitions of spectacles on and off. All other markings and numbers appear once the examiner submits their final markings. The pink and purple solid horizontal lines indicate subject reported spectacle on time and whether or not the sensor was covered by their hair. The blue, yellow, and green solid horizontal lines indicate the location (indoors, outdoors, or in car) of the sensor. Manual time worn (bottom right side) is calculated once the examiner submits their markings. Device time worn indicates subject reported wear time and is visible upon completion of the examiner markings.

Figure 3.

A, B, C Wear patterns of eight subjects with high quality logs for Week 1. Striped bars indicate particular subjects and weeks with absolute per cent error greater than 20% by one or both examiners. A trend can be seen in which the subjects with greater error consistently had less total wear time (*Figure 3A*) with more frequent ON/OFF transitions (*Figure 3B*), resulting in shorter durations of continuous wear time (*Figure 3C*).

Figure 4. Temperature versus time plot for Week 1 data of Subject 9. For the majority of the week, the spectacles were left in a car that was parked in an unshaded area (yellow dots/line). Periods of spectacle ON time were very brief and only represented a small portion of the week (pink and purple dots/line).

Table 1

Example wear-time log provided to study participants

Date	Time	Specs ON / OFF	Hair Covered Sensor YES / NO	Additional Details (environment/activity)
June 5	7:35 AM – 11:45 AM	ON	YES	Woke up, drove to work, sat in office
June 5	11:45 AM – 12:00	ON	YES	Walked outside in 100° F heat
June 5	12:00 – 12:30	ON	YES	Lunch inside
June 5	12:30 – 12:45	ON	YES	Walked outside in 100° F heat
June 5	12:45 – 6:30 PM	ON	YES	Work, drove home
June 5	6:30 – 7:30 PM	ON	NO	Exercised
June 5	7:30 – 8:00 PM	OFF		Showered – glasses on bathroom counter
June 5	8:00 – 9:00 PM	OFF		Glasses tucked in shirt pocket
June 5	9:00 PM	OFF		Glasses on nightstand

Table 2

Mean [SD] data logger temperatures (°C) categorized by subject wear logs

	Group* (n = 50)	Male** (n = 18)	Female** (n = 32)	Adhesive (n = 23)	Silicone (n = 27)
ON	31.8 [0.6]	31.2 [1.7]	32.2 [1.1]	31.5 [1.6]	32.0 [1.2]
OFF	24.7 [1.5]	24.2 [2.0]	24.9 [2.1]	24.3 [1.8]	25.0 [2.2]

* Group mean ON & OFF temperatures differed (p<0.001)

** ON & OFF temperatures varied by gender (p=0.04)

Table 3

Classification of Absolute Percent Error (Q1, Q3) in Approximated Wear Time using Different Strategies

	Group Mean Filtering	Individual Mean Filtering	Examiner 1	Examiner 2
Median Error (Quartile 1, Quartile 3)	8% error (3%, 18%)	7% error (4%, 19%)	6% error (2%, 14%)	7% error (3%, 12%)
10% Error	32 subjects (64%)	32 subjects (64%)	35 subjects (70%)	35 subjects (70%)
11 – 20 % Error	9 subjects (18%)	5 subjects (10%)	6 subjects (12%)	8 subjects (16%)
> 20% Error	9 subjects (18%)	13 subjects (26%)	9 subjects (18%)	7 subjects (14%)

Table 4

Percent error for each approximation method for subjects with high confidence logs.

	Subject #	1	2	3	9	11	19	23	41	Median
<i>Week 1</i>	Examiner 1	2%	4%	-1%	37%	9%	-8%	14%	2%	3%
	Examiner 2	18%	8%	-7%	10%	0%	-2%	7%	-5%	4%
	Individual Mean Filtering	5%	-5%	-8%	147%	-10%	7%	1%	11%	3%
	Group Mean Filtering	9%	3%	10%	136%	-6%	15%	2%	20%	6%
<i>Week 2</i>	Examiner 1	2%	-1%	1%	32%	-1%	-9%	5%	2%	2%
	Examiner 2	0%	1%	1%	47%	2%	-64%	4%	1%	1%
	Individual Mean Filtering	0%	8%	-12%	179%	-12%	7%	-6%	-4%	-2%
	Group Mean Filtering	-4%	15%	0%	118%	-12%	11%	2%	-1%	1%
<i>Week 3</i>	Examiner 1	1%	0%	1%	139%	3%	21%	7%	-4%	2%
	Examiner 2	3%	5%	8%	160%	3%	7%	9%	-7%	6%
	Individual Mean Filtering	48%	-7%	-3%	328%	-5%	5%	-2%	-6%	-3%
	Group Mean Filtering	83%	0%	1%	233%	4%	21%	-4%	-10%	3%
<i>Week 4</i>	Examiner 1	5%	4%	-7%	22%	-4%	40%	1%	9%	5%
	Examiner 2	5%	4%	0%	-61%	-6%	54%	0%	14%	2%
	Individual Mean Filtering	-7%	-4%	-9%	76%	-9%	11%	-7%	3%	-6%
	Group Mean Filtering	5%	1%	-1%	93%	-9%	45%	-12%	-1%	0%

[†] Positive values indicate overestimation of wear time and negative indicate underestimation of wear time. Subjects with greater than 20% error are shaded in gray.

Table 5

Examiner 1 percent error for week 1 wear at different sampling intervals

Subject #	1	2	3	9	11	19	23	41
5 Min Sampling	2%	4%	-1%	37%	9%	-8%	14%	2%
20 Min Sampling	13%	0%	-1%	-20%	-5%	30%	10%	2%
30 Min Sampling	11%	6%	-2%	-12%	-1%	18%	10%	11%
60 Min Sampling	-12%	-11%	1%	30%	20%	-5%	-6%	-3%