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Enhancing Mobile Eye-Tracking in Extreme Urban Lighting Conditions

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Abstract. One of the methods for understanding residents' needs and socially improving urban spaces in terms of transportation, safety, landscape protection, and managing tourist traffic load is eye-tracking (ET). Researchers using mobile ET for outdoor studies face significant challenges, particularly due to sunlight affecting data quality. Existing solutions often overlook participant comfort. This article introduces a novel accessory designed for extreme lighting conditions, such as bright days, sunsets, and snowy or water-filled environments. The goal is to eliminate disruptions caused by uncontrolled sunlight on participants' eyes and enables studies in urban environments. A custom sun shield, designed for ETs based on spectacle frames, prioritizes both physical and psychological comfort. The lightweight shield is easy to install, minimally restricts the field of view, and does not interfere with eye-tracking components. It is cost-effective and suitable for DIY 3D printing. Control studies and field research confirmed its effectiveness, with feedback from over 100 users improving the final design. The shield enhances eye-tracking research credibility in sunny conditions, supports efficient calibration, and improves participant recruitment and well-being. Jakość danych znacząco wzrosła co obrazuje porównanie danych dotyczących sposobu detekcji źrenicy. Thanks to this solution, it will be possible to conduct research aimed at better understanding the behavior of city users, while ensuring their comfort and safety. It will also be possible to conduct research within the framework of so-called living labs. Importantly, studies show that the approach to designing subsequent mobile ETs based on IR should undergo significant modification.

Key words: outdoor eye-tracking, smart city, data quality, calibration, sunlight

1. INTRODUCTION

Video eye-trackers (ET) are based on estimating the position of the pupil center relative to the infrared (IR) light reflections on the cornea of a fixed light source, e.g., usually small near-IR Light Emitting Diode (LED) or multiple LEDs [1]. The use of IR allows indicating the direction in which the participant is looking. The light itself invisible to the participant. One type of ET includes mobile devices. With them, research can be conducted in motion [2], in various cognitive situations, also outside of laboratories and building interiors [3]. This type of device is typically worn on the participant's head. These ETs can be attached to helmets, straps, bands, and frames. Almost everyone wears or has worn glasses at some point (corrective, sunglasses, protective), so the most cognitively natural approach seems to be the use of glasses or frames worn on the nose and ears. Glasses are also an element that other people are less likely to notice.

ET are utilized as sensors in smart objects [4], contribute to human-computer interaction [5], and assess or enhance product design [6]. This applies to various objects and activities, including those carried out in natural and urban spaces; while walking [7], driving [8], cycling [9], working [10], while practicing sports [2] or in combat [11]. Field studies can be conducted under various lighting conditions [12]. A technological challenge affecting the performance of ET is the situation in which intense sunlight hinders effective research [13]. There are at least two aspects of natural lighting influencing the deterioration or lack of data [14]. Firstly, there is glare – when participants partially or completely close their eyes [15]. This effect prevents the diagnosis of cognitive load based on the number of blinks or eye-openness [4]. It diminishes the percent of collected gaze data. The second element negatively affecting the feasibility and quality of studies conducted in highly sun-exposed areas is the additional IR reflections generated on the eye due to sunlight. This is a problem noticed by many researchers from various fields. Solutions offered by manufacturers (protective covers, sunglasses, and polarized lenses), despite their assurances, are often insufficient [14]). In brightly lit areas, calibration, which allows for considering the influence of individual

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characteristics of the participant on the measurements, is often impossible. The number of data collected per unit of time drops to levels below 40%. This means, for example, that for a 120Hz ET, less than 50 eye positions are diagnosed per second, indicating that these data are not evenly distributed over time (no continuity). Interpreting eye positions based on randomly recorded fixations and saccades is impossible because there are many interferences. The gaze path recorded by the device could look completely unbelievable (illogical fast jumps with extreme amplitude and random direction).

Literature reviews reveal how scientists have attempted to prevent both of these unfavorable situations:

●they conducted studies exclusively under overcast sky [9]
●they used shading roofs [16]
●they asked participants to wear large Mexican hats [17]
●they constructed helmets with a shield made of special foil as face shields [7]
●they proposed the use of tined or photochromic lenses [14].
●some even abandoned optical eye-tracking in favor of electrooculography [11].

What is important is that the problem is common, noticed and described more than 10 years ago (2012-2023) and affects many products (types were indicated in brackets). In some articles, there are no sections reporting such problems [18], which from a methodological point of view seems to be an oversight. It should be noted that in many cases, despite the applied shields, data quality still raised doubts. However, scientists using these solutions did not discuss the impact of narrowing the field of view, head load on the focus of the participants [19]. Individual solutions caused additional reflections ([7] - video abstract 1:00-1:35). Some of these projects might have looked unusual because the research was conducted in isolation [7]. However, this is not permissible when participants are supposed to act as naturally as possible in urban space. The design of the apparatus can influence the behavior of the participants and people around them. As a result, the research findings become less credible. It is also essential that without access to the project of the changes made, the research cannot be verified or continued (the presented studies do not meet the basic criterion of scientific credibility). Additionally, the unusual appearance of additional eye-tracking elements (shape, size, color), their weight, and the long time needed for its proper installation could hinder or even prevent their use in tests on randomly recruited participants. The need for an unfavorable limitation to individuals who may know the research goal or be professionals is mentioned by de la Fuerte Suárez [20]. These are all very important distractors that need to be avoided. Due to calibration issues and data loss, a significant portion of research, despite focusing on urban spaces, areas beyond buildings, and landscapes, is conducted in laboratories. The method of assessing gaze is based on photos [21], visualizations and photomontages [22], videos games or VR technology [23]. It is crucial to conduct and compare test results in different environments as often as possible. Currently, due to technological reasons, this is often impossible. Data acquired in intense and/or directly shining sunlight on the participant's face are usually of poor quality [24]. This issue was encountered in July 2023 during the preparation of research on the perception of Ostrow Tumski in Wrocław. Participants were supposed to walk along a sunny boulevard by the river. Originally, data were to be collected using Tobii Glasses 3 + protective tinted lenses [25]. In the summer's intense sunlight, especially with the low sun and near the river, the data quality was inadequate. During the research, calibration of the device was often ineffective, and when registration started in the shade, the device could not frequently indicate the participant's gaze direction during the walk. Conducting research in this way would result in a massive loss of data.

Similar to studies described in the introduction, attempts were made to conduct registrations with a cap with a visor, a high-crowned hat, and even a hood. None of these methods were satisfactory near the river, where the atypical, bottom-up direction of sunlight penetration under the eye tracker remained problematic. The effect was partially eliminated by applying black lipstick/face paint or dark adhesive bandage (size around 3x4cm) just below the lower eyelids. However, this solution was deemed unacceptable by recruited passersby (strange appearance, potential allergic reaction, makeup smudging, the need to touch the participant, difficulty in removing the paint) and unnaturally drew the attention of others. Due to the ineffectiveness of previous solutions or their negative impact on research results, it was deemed necessary to design an element that would enable one to conduct studies in a wider range of real-life situations. The new solution was intended to facilitate research near water bodies (beach, lifeguard training, navigation, sailing, landscapes, waterfront urban planning), outdoor sports studies (equestrianism, cycling, tennis, skiing), and research conducted at different times of the day associated with the sunlight's unfavorable direction for eye-tracker operation (morning - sunrise, evening - sunset) and seasons (in winter with a dazzling effect from the snow cover).

Expanding the range of locations where reliable research using ET can be conducted is crucial for the socially responsible design of sustainable urban spaces that cater to the needs of diverse users. These include residents, tourists, cyclists, people with disabilities, and individuals performing outdoor work such as rescue workers, municipal guards, police officers, and construction workers.

2. AIM

The new element is intended to be an effective, affordable, easy-to-use accessory for ET glasses. Considering usage guidelines and warranties, the solution should not modify other components of the eye tracker and should be universal enough that, with slight modifications to its design, its operating principle could be applied to different mobile eye trackers. Originally, the goal was to create an idea allowing for universal use in all such eye trackers, as shown in the sketch presented in figure 1. It was decided that the accessory must block light from three directions: from below, from the side behind the ear, and from above. The need to change the design approach for ET devices intended for use in the field will be verified by examining three key aspects. Whether complete shielding of light from all directions will: support proper pupil detection by mobile ET devices, enable or shorten the calibration procedure, and impact the percentage of collected data. Beyond achieving the primary technical goals, the article aims to present the next design stages focused on modifying the method of blocking light, taking into account other factors such as material properties, aesthetics, psychological, economic, and ergonomic aspects. The additional objectives are characterized below. The issue of fitting and installation needs to be individually addressed. The issue of fitting and installation needs to be individually.

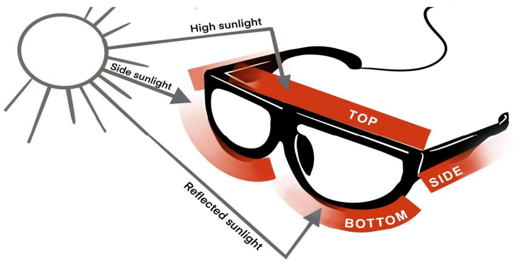

Fig.1. Idea. Concept sketch of the shield.

The connection between the shield and the frame must not be permanent or carry the risk of damaging the devices and accessories covered by the warranty. The design of the new element should meet high standards to ensure that participants feel comfortable both physically and psychologically. The casing should be lightweight, stable, easy to install, and minimally restrict the field of view. Aesthetic solutions were sought, and the colors and materials used should be similar to those applied in the modified device. The casing should allow for disinfection or be disposable. It was important for the solution to be cost-effective, even feasible for DIY production.

3. MATERIAL AND METHOD

To identify the most suitable ET device for research purposes, we sought a model that, according to the manufacturer's descriptions, would be best suited for conducting studies in environments with intense sunlight. Additionally, considerations included user comfort, aesthetics (appearance resembling regular glasses), and the ability to customize the device to meet participants' visual needs (vision correction, eye protection). Based on a literature review (see introduction), we analyzed data on various ET devices used by researchers, who reported difficulties in conducting studies under direct sunlight. The devices reviewed included ETVision, VPSNeon, Tobii Glasses 2, Tobii Glasses 3, Pupil Labs, ASL Mobile Eye-XG, Positive Science, Pupil Labs, ASL Mobile Eye-XG, SMI Glasses 2.0, and aSeeGlasses. ET devices were eliminated from consideration if they were: no longer available on the market, tracked only one eye, required a laptop instead of a portable device, lacked Wi-Fi functionality, or recorded eye position data at a frequency lower than 60 Hz, or lacked solutions that allowed for the correction of participants' visual impairments.

After the analysis, Tobii Glasses 2 and Tobii Glasses 3 were selected. Since it was demonstrated that Tobii 3 outperformed Tobii 2 in terms of accuracy during walking trials [26], the analysis was conducted using the newer generation device.

According to the conducted review, the selected ET has the greatest potential for conducting scientific research in conditions of intense lighting. The full device specifications are available on the manufacturer's website. It includes descriptions of the tinted protective lenses (15%) designed to block 850 nm IR waves [25]. The product description states: "With a discreet design, our protective lenses fit snugly over Tobii Pro Glasses 3, providing the wearer with optimum comfort and freedom of movement — enhancing the accuracy of data capture and lowering the impact of external influences, such as sunlight and nearby objects." As per the mentioned concerns in the introduction, the factory solution proved unsatisfactory. Before starting the project verification of the described parameters and additional measurements were carried out. The spectral transmittance of the dark tinted filter on protective lenses was measured (fig.2) with the UV-VIS spectrophotometer METASH V-5100. Spectroscopic assessment was performed in accordance with the European standard ISO EN 12312-1 and compared against it. It is an European standard test on UV transmittance and categorized the four filter levels (0-4). Additionally, the British standard test sunglasses against their UV transmittance. All sunglasses that meet this standard will carry the 'CE' mark or 'UV 400' which should be visible on the sunglasses. One can see that this attachment fulfills the criteria for sunglasses with a filter of category 3 (dark tint). This filter has a transmittance below 18% in the visible light spectrum and protects the eye against harmful UV light below 400 nm in wavelength. This filter category is most suitable for very bright weather or water or snow sports where light is reflected.

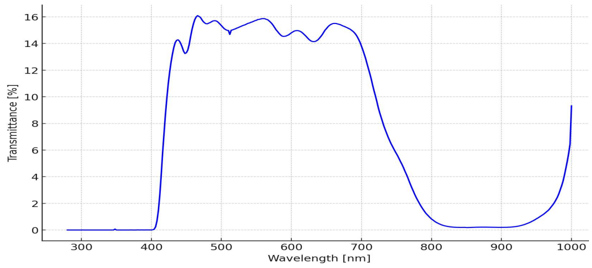

Fig.2. Spectral transmittance of the dark filter attachment of Tobii Glasses 3.

3.1. Description of the Designed Element

The shield is slid onto the included Tobii Glasses 3 polycarbonate protective lenses (tinted), and then, along with the shield, is mounted on the ET. The casing's design allows for filling gaps between the eyeglass frame and the test subjects' nose wings, forehead, jaw, cheekbones, and temples. The shield prevents uncontrolled entry of sunlight from the sides, top, and bottom of the device. The shield does not touch or obstruct any functional elements of the ET, such as cameras, LEDs, or mounting magnets (fig. 3). The project was modeled in Blender 4.0 based on a photogrammetric scan of the ET's protective lenses using AgiSoft Metashape Professional. Due to the impossibility of scanning transparent objects, the eye-tracker was covered with an opaque layer (50 photos from different directions were taken). The shield for studies in

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extreme lighting conditions consists of two parts. The first part (1) is a black plastic mounting element (frame). The element was printed from PETG using a PRUSA i3 Mk3 printer. The second part (2) is a black flexible material filler – a gasket. In the illustrated example, it is a sponge, but it is also acceptable to make it from black, soft rubber (fig.3, fig.4). The advantage of the second solution is the absence of the need for drying after disinfection with a surface-active agent.

Fig.3. Shield and its mounting mechanism (1. eye-tracker; 2. protective lens [25]; 3. shield FV)

3D printing of the frame (V1 and FV) took approximately 7 hours, assuming a cubic infill level of 30% and a layer thickness of 0.15mm. PETG filament was used, with a consumption of approximately 49g (V1) and 35g (FV). Additionally, 2-3 hours was dedicated to attaching foam padding (V1) or blocking rubber elements (FV). The cost of purchasing materials for making the V1 shield in 2023 was less than 5EUR / 5$. The V1 shield is easier to print "at home", the FV version requires more advanced equipment - that fore is more expensive (cost of the commercial print order was estimated at 350-500 EUR/$.

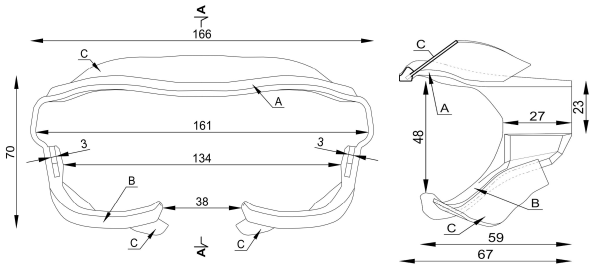

Fig.4. Frontal view and cross-section [mm] A- 3D printed PETG frame, upper beam; B- 3D printed PETG frame, lower half beams; C- Polyurethane foam 25kg/m3 glued to the frame.

4. RESULTS

For the created concept, to examine how physically blocking side, top, and bottom light would affect the performance of the ET, several control studies were conducted. The first concerned comparison of pupil diameter measurements. The second involved effectiveness tests (V1). The third was partially connected with the fourth and included comparative measurements of the impact of the shield on the comfort of users and their field of vision (V1 and FV). Last test compared the appearance of the eye tracker (ET) without and with the shield (V1 and FV).

4.1. Pupil diameter measurements and effectiveness

To present the difference in the quality of data collected without and with the shield, a comparison was made of how the device performed in detecting and recognizing eye pupils. Charts are based on raw data from TobiiProLab (fig.5) and represent pupil diameters of 3 healthy participants walking on a sunny courtyard (Wrocław, 21.10.2023) while performing a task that required looking in various directions and continuously moving between shaded and sunlit areas. Measurements taken without the shield show numerous inconsistencies. Considering the study location, measurements indicating a pupil diameter of over 8mm for a participant are unreliable. Measurements taken with the shield show very good data quality in two cases. Measurements for Participant 2 have significantly improved, but they are still not ideal (max. 6,8mm). The comparison reveals that the use of

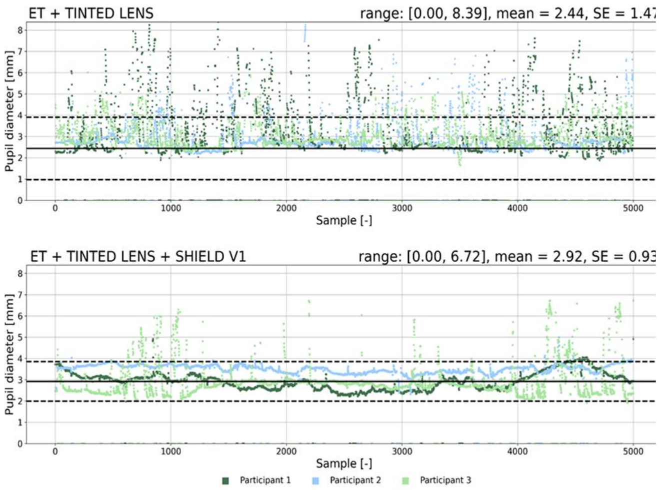

Fig.5. Comparison of pupil diameter measurements without and with sunshield. Upper graph: range: [0.000; 8.387], mean: 2.439, standard deviation: 1.467: Lower graph: range [0.000, 6.723], mean: 2.923, standard deviation: 0.932, Solid line: mean, dashed lines denote margin of ± standard deviation.

the shield resulted in an increase in pupil diameter, the shield blocks out some light and eliminates glare. Initially, comparative studies were conducted on 20 participants (students of various genders, aged 19-24 y/o, without vision impairments such as strabismus, functioning without habitual optical correction, with different physiognomies, body masses, and heights). Participants were recruited from a group of passersby. Volunteers were not remunerated. After explaining the purpose and course of the study, participants gave their consent to participate and, in accordance with ethical principles, could withdraw from the tests at any time. The tests were conducted on a courtyard illuminated by bright panels (51°07'07.6"N 17°03'14.6"E) during clear weather in October and December, with the sun positioned low and in as similar position as possible (morning 8:00-10:00). Participants, standing at a designated point, were tasked with looking twice, in the appropriate sequence, at several architectural elements surrounding the courtyard. Body and head rotations resulted in different positions of the ET relative to the sun. Observed objects were located low (participants lowered their heads), at eye level, and high (participants raised their heads). The task was performed once without the enclosure, only with the protective glasses provided by the manufacturer (tinted) (fig.5).

The second repetition was performed with the additionally applied cover (fig.5). The registration sequence was alternating (10 times WI-WII / 10 times WII-WI). The studies were conducted under a cloudless sky. Participants spent from 24 to 37 seconds on the task. Table 1 shows the results of the enclosure effectiveness tests are shown.

Table 1. Results of simulation

Location 51.118771N 17.054067E	Without shield with tinted protective glass		With shield (V1) with tinted protective glass	
P-Participant	% data*	calibration attempts	% data*	calibration attempts
1	**36%**	II	68%	I
2	-	IV	63%	I
3	69%	I	83%	I
4	80%	I	88%	I
5	**58%**	III	85%	I
6	84%	I	94%	I
7	88%	I	91%	I
8	-	IV	-	IV
9	81%	II	84%	I
10	83%	I	93%	I
11	91%	I	96%	I
12	**44%**	II	**49%**	III
13	96%	I	90%	I
14	67%	I	78%	I
15	**46%**	III	69%	I
16	95%	II	91%	I
17	**59%**	I	91%	I
18	-	IV	**58%**	II
19	67%	I	83%	I
20	-	IV	83%	I
summary	4 P. without calibration 5 P. with poor data **65% recordings could be used**		1 P without calibration 2 P with poor data **85% recordings could be used**	

In 3 out of 20 cases, the application of the cover allowed for successful calibration, which would not be possible without the shield. In one case, the cover did not resolve the calibration issue; this pertained to an individual with long upper and lower eyelashes. The frame positively influenced the research flow. For 8 individuals, the frame reduced the number of necessary calibration attempts (on average by 2 attempts). However, for one out of 20 individuals, the number of calibrations with the cover was higher. In 15 out of 20 cases, the data quality increased from 3% to 83%, with an average increase of 23.2%. In two cases, after applying the cover, effectiveness was lower (by 4% and 6%). It is noteworthy that the quality of collected data in those two cases without the cover was initially very high (95-96%), but after using the cover, it decreased to the level of 90/91%. Additionally, recordings in variant WI turned out to be inappropriate for further interpretation in six cases, and in variant WII, three cases were unsuitable. In total, in 10 cases, WI data, and for 3 cases, WII data had to be deemed ineffective or faulty because the time during which the device was unable to register the gaze direction exceeded 40%.

The cover positively affected all aspects of research. A significant success is the considerable reduction in data loss (at a level of 20%). Wilcoxon signed-rank tests showed that both number of attempted calibrations and effectiveness of data sampling significantly improved ($p<0.05$). This not only signifies time and cost savings but also enhances the credibility of data interpretation. These findings are supported by field research conducted near a watercourse [28]. During landscape studies, 82 people were recruited, and after considering all methodological exclusion aspects (accidental exclusion, battery depletion, camera obstruction by bangs, failure to perform the task, talking on the phone, removing the ET), recordings of 62 individuals remained (75% of the data). Without the cover, data would be just over 50%.

After the described tests and field studies (September 2023 in the center of Wrocław, Poland), during which over 100 people used the shield [27], it was observed that the effectiveness of the cover varies and depends on the structure of the participants' facial anatomy (cheekbones, face width, nasal bone) and eyes. Despite using foam on the inner side of the cover, in some cases, it was not possible to eliminate translucency due to the less prominent structure of the zygomatic bones in some participants. The material and shape of the shield required modification, also because people with wide nostrils or prominent mouths reported itching when speaking. There were also remarks about slipping off the nose, the feeling of the frame being repelled from the face, the large size, the sense of the environment. During the research, it was noticed that the casing is not controversial, but attracts the attention of passers-by much more than ordinary glasses. For this reason, an analysis of the appearance and subsequent modifications described below were undertaken.

Due to the need to refine the appearance of the V1, the following changes were introduced to the final version: strengthening the joints, reducing the amount of filament used (cost and weight), changing foam to rubber (enables disinfection), ensuring ventilation.

4.2. Aesthetic Comparison.

Primarily, the tests aimed to verify to what extent additional accessories (V1) influenced the way participants were perceived by other individuals in the nearby space. It proved impossible to maintain the unchanged appearance of the person being examined due to the necessity of enclosing the space between the ET and the face. Additionally, it was necessary to insert a layer adapting to the shape of the face. Because of the added weight only at the front of the ET and thus shifting the center of gravity, it is necessary to use the original glasses stabilizing strap, which also affects participants' appearance (not many people are using them in real life situations with regular corrective glasses). Despite these features, the device does not overly attract attention from passersby, as observed during recordings conducted in Glasses with the casing do not disrupt the perception of the silhouette from a distance greater than 5 meters. At a closer distance there is a noticeable change in facial proportions while wearing V1 of a shield (fig.6. C/D). This applies to both women and men when seen from the front and from the side. ET with V1 shield is similar to ski goggles or VR glasses, the image of which is already widely present in public consciousness, but it is unusual in real life situations. Design work at this stage of research consisted of reducing the external size of the shield and material tests. Particularly important was the reduction of the size of the elements overlapping the forehead and cheeks. The introduced modifications led to the creation of the final version of the shield (FV) (fig.6 E). Shield FV has a much smaller impact on the perception of the figure and face of people wearing the device.

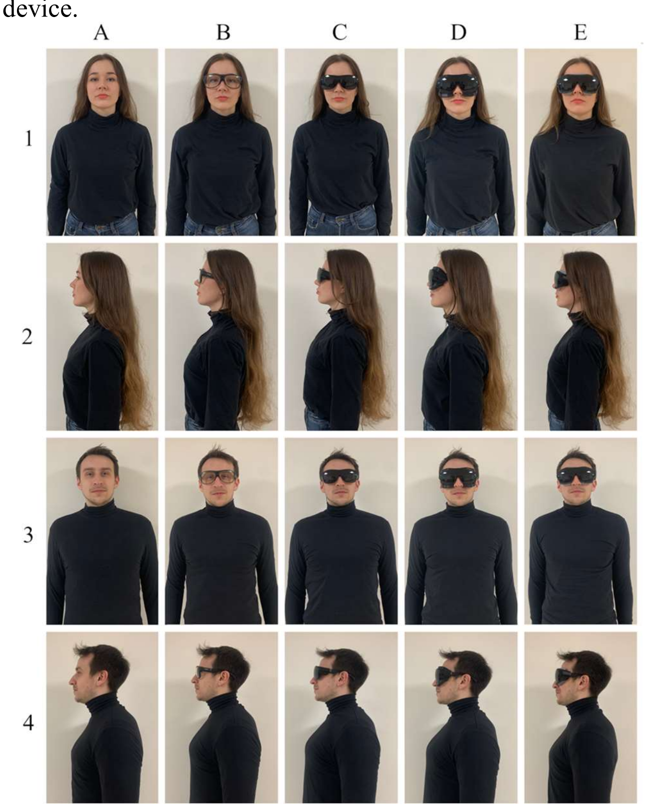

Fig.6. Device Appearance and Analysis of the Perception Difference in a Person Wearing an Eyetracker: A - Without eye tracker, B - With eye tracker, C - With eye tracker and sun visor, D - With eye tracker, sun visor, and the designed shield V1 (first version), E- With eye tracker, sun visor, and the designed shield FV (final version); 1- female silhouette, frontal view, 2- female silhouette, side view, 3- male silhouette, frontal view, 4 - male silhouette, side view

4.3. Impact on the Field of Vision.

To quantify the fit of the design and adjust it, the impact of the optical aids on the subjects' field of vision was assessed by using the binocular Esterman visual field test (EVFT). Measurements were performed with an automated projection perimeter PTS 2000 (Optopol, Poland, www.optopol.com.pl). EVTF was originally designed to predict an individual's mobility (walking), currently being used as a visual field test for determining fitness to drive in the UK. It presents a bright white light stimulus (10dB) at each of the 120 locations within the visual field in 75 degrees horizontal and 55 degrees vertical ranges, arranged in a pattern. During the measurement subjects were required to fixate on a red small target that was displayed in the center of the device and press the button whenever they see a white light in any parts of their visual field. Static field of view was assessed. Each measurement results with a map of points in which subjects were or unable to see the white light, enabling qualitative assessment of the impact of the shields and/or ET frames on the observers' field of vision and aid further improvements to be implemented in the design.

Measurements were performed on 12 subjects (6 males and 6 females; 19-56 years old), in 3 different set-ups. To ensure that subjects have no visible impairment (scotomas) in their field of vision, the first round of visual field measurements was performed on subjects' wearing no additional attachments or any means of vision corrections. Therefore it was assured that subjects are able to see the targets without their habitual corrections, which additionally implies subjects' refractive correction was limited to approximately 4 dioptres of myopia. Subjects who did not pass this part of the test were excluded. Second test was performed on subjects wearing the eye-tracking glasses and the third measurement was performed with any subsequent version of the shield (V1 or FV). Each of these measurements was approximately 2.5 minutes long (depending on the subject's response time). It is worth noting that the impact of the shield or eye-trackers on the subject's field of vision (static field) cannot be directly regarded as an impact on the subject's field of view (when the eyes are moving). Therefore one cannot make clinical claims on the subjects fitness to drive from the results of the perimetric testing shown below. This assessment, however, can be used to quantitatively assess the fit of the shield or ET-glasses, allowing objective comparison. At figure 7 we summarize the results of the perimetric measurements performed on 12 subjects.

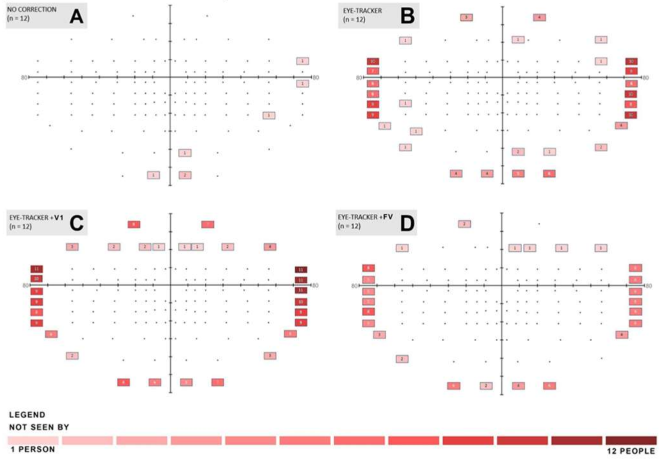

Fig.7. Summary of perimetric measurements for the group of 12 subjects. Color and numbers written in brackets correspond with the number of subjects that did not see the corresponding point in their field of vision. A- measurements without any optical aids on B- measurements with eye tracker glasses on; C- measurements with ET and Shield V1; D - measurements with ET and shield FV.

As we can see from the examples above (fig.6A), subjects without any additional optical aids made only some minor errors in the Esterman test. These mistakes however do not qualify as clinically significant errors. Therefore, the group of subjects tested could be included in further analysis.

As shown in the figure 5B, ET glasses frame impacts both peripheral temporal parts of the field of vision (75 degrees on the left and on the right) and this change could be considered clinically relevant if the test was performed for the purposes of licensing Group 1 car and motorcycle driving in the UK.

This is most probably caused by the temples of ET-glasses covering a larger portion of this part of the field of vision. Some subjects display errors in their upper field of vision, which is most probably due to the glasses sliding down or sitting lower on the nose. This points to the fact that even with the interchangeable nose pads of different sizes, that are provided by the manufacturer, the ET-glasses frame cannot be firmly fitted and secured in all subjects or sits lower on the nose due to individual anatomical features of the subjects' face structure. Additionally, the nose pads make the ET-glasses move further away from the wearer's face (increase the vertex distance) and this results in the frame being more visible as it moves to the central parts of the field of vision. The full set of attachments installed (V1) impacted both vertical and horizontal meridians in the external parts of the subjects' field of vision (fig. 6C). In case of V1 the impact of the cover was larger that of the ET-glasses, which is most probably caused by the temporal parts of the shield covering a substantial part of the field of vision in a horizontal meridian. Additionally, because of the padding installed in the V1 the cushioning action makes it more difficult to firmly attach the set to the subject's face. Soft padding in the temporal part of the shield covered the field of view in the horizontal meridian compared with ET glasses. The V1 version of the shield must be more firmly attached with the strap and supported by extra nose padding to prevent it from sliding down from the subject's face and covering the upper and lower field of view. Taking the impact of the V1 shield on the subjects' field of vision improvements were made and another version of the shield was designed and manufactured.

As predicted, the FV shield impacted the field of vision in both horizontal and vertical meridians and its impact on the subjects' field of vision is lower than that of the V1 (fig. 6D). What's interesting is the fact that ET itself seems to limit the field of vision more than the final version including the ET glasses and FV casing. This might be due to several technical factors that characterize this new design, which include:

●As mentioned earlier, the interchangeable nose pads of the ET-glasses provided by the manufacturer do not fit all subjects with diverse facial features and nose structures and in these subjects glasses may be sliding off even when secured with the strap. Application of the nose pads additionally increases the vertex distance, which was shown to be a parameter that narrows the field of vision.

●The rubber collars around the casing of FV make the casing sit more stably on the nose, rests higher on the face and prevents it from sliding off, which resulted in less impact on the upper and lower portion of the field of vision in those subjects.

●Additionally, the FV does not obscure the temporal parts of the field of vision as the V1. This part of the field of vision is already covered by the transparent anti-glare attachment provided by the manufacturer.

●It was shown that the spectacle frame may have less impact on the field of vision in subjects with larger pupils [28]. The increase in pupil diameter caused by a decrease in the amount of light reaching the eye could add to the observed differences in the field of vision. This also may provide a valid reason for prescribing tints for daytime driving.

●the FV frame is thinner than that of the V1 obscuring smaller areas in the field of vision.

●The FV is placed closer to the face than all the other solutions applied, and the decreased vertex distance enables a wider, unobstructed field of vision.

The ET-glasses frame does not allow adjusting the frame to the subject's interpupillary distance (PD), which would further improve the field of view in some subjects with smaller faces. Taking into account the impact of the FV on the field of vision no further improvements in the design of the shield were advised, resulting in the final version of the shield design.

5. DISCUSSION AND CONCLUSION

The idea and the operating principle of the shield have been submitted as an invention - Application WIPOST 10/C PL 447199. In the case of further development, material strength tests of FV should be conducted. The shield, even when damaged, should not create sharp edges or fragments. Additionally, the idea of the shield can be adapted to eye trackers of other brands. Various mounting options should be provided for individual models and adding a glass tinted cover should be considered for models that do not originally have such solution provided.

Although data shows that pupil diameter measurements vary wildly without the shield and those with the shield in place appear to be much more in line with expectations, there is still a need for future testing of the impact of the shield on eye tracker accuracy. This is because the method of camera-based eye trackers typically relies on estimation of pupil center in relation to corneal reflections of the near-IR light sources, it is not clear how changes in pupil diameter might affect estimation of pupil center. It may be that the center of the ellipse that is typically fit to the pupil limbus is unchanged but this requires further testing of eye tracker accuracy and precision, i.e., a validation study is planned as future work.

The shield designed and presented by our interdisciplinary team enables conducting studies in urban and landscape environments using the Tobii Glasses 3 eye tracker even on cloudless, very sunny days, near bright and light-reflecting objects. This expands the possibilities of using eye tracking for scientific and commercial research. This enables broader applications in so-called living labs. Possible new applications include: research near or on water (sea, lake, river); studies of athletes outdoors (horseback riding, tennis, skiing); studies at different times of the day (morning, sunset);

The strengths of the final solution include:

●small size and weight; easy assembly and disassembly;

●effective calibration, possible not only in shaded areas;

●significant improvement in data collected in fully sunlit locations;

●elimination of reflections occurring on the inner side of ET lenses;

●possibility of DIY production and low cost.

The project meets almost all the assumptions arising from the initial needs analysis; however, further use and testing have identified additional design challenges: increased dimensions of the eye tracker; extended study time because of the need for disinfection; increased risk of an accident while driving (limiter field of view; the additional frame may cause lens fogging.

In everyday life, we increasingly use optical solutions such as lenses with filters or variable transparency, tailored to individual vision protection needs. A similar approach could be considered for ET technology, particularly in the context of dynamically changing lighting conditions in urban environments. People, as they move, change positions, enter or exit buildings or vehicles, are constantly exposed to fluctuations in both natural and artificial lighting. In the future, research on mobile ET systems should focus on verifying the reliability of data collection under low-light conditions, which requires the use of new types of scene cameras. Additionally, implementing intelligent coatings and parallel image recording with cameras of various technical specifications will be essential. A critical task will be to assess how these innovations impact data quality and experimental outcomes. Another challenge for ET technology is conducting studies during the rain, in fluctuating temperatures, or in high humidity, which can lead to equipment fogging and malfunction. Addressing these difficulties calls for an expansion of available accessories and dynamic, close collaboration between equipment manufacturers and the scientific community. Only through such efforts can ET technology be effectively developed and adapted to the realities of everyday life and scientific research.

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