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# Visual and optometric issues with smart glasses in Industry 4.0 working environment

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**ABSTRACT**

Smart glasses are a kind of Head Mounted Display (HMD) with great potential in Industry 4.0 working environments, where shop floor workers must be supplied with critical information in a timely, accessible and safe manner to be as productive as possible. Smart glasses collect data from a wireless network and project it on a tiny screen before the user's eye. Despite several benefits, such as hands-free access to computer-generated info, routeing to storage locations, eliminating the need to carry handheld scanners or written documents, there are also possible problems evidenced from the literature. HMD can cause headaches, pressure in the eyes, problems with focusing and difficulties with text reading. To study the addressed problems, a research was performed together with Ophthalmologists from Maribor Healthcare Centre. The effects of using Vuzix M300 Smart glasses on users' comfort during order picking activities were researched in a testing warehouse environment at the Faculty of Mechanical Engineering, Maribor. The testing period lasts four hours. Several ophthalmologic tests (visual acuity, contrast sensitivity, visual field testing and colour test) were performed before and after use of smart glasses. Results show that there are some statistically significant differences before and after use of smart glasses in users' visual acuity and, surprisingly, a high percentage of scotomas in the right eye (where the projection of smart glasses was performed) after use of smart glasses that cannot be overlooked.

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## 1. Introduction

Radical transformation of the manufacturing systems under the aegis of Industry 4.0 is facilitated by the concurrent development of disruptive technologies and the digital era. Factories are becoming smarter and more information-rich. For the first time, we have (evolving) technologies that can supply shop floor workers with critical information in a timely, accessible and safe manner to be as productive as possible. Smart glasses are a representative piece of equipment that makes that possible [1]. It lasted less than four years from the first public presentation of Google Glass to the first commercial use of smart glasses in the industrial environment. In the paper, we focus on manual order picking, as an example of a production working environment in a transition to Industry 4.0, and on the usability of smart glasses, as an example of industry 4.0 enabling technology.

Most order-picking systems used in practice are manual "picker to part" systems, and more than 80 % of all orders processed by warehouses are picked manually [2, 3]. The order picking process, a process in which humans are routed by picking lists to items' storage locations to retrieve items for customers, is the most laborious and the most costly activity in a typical warehouse. With up to 55 % of the warehouse total operating costs [4], it is obvious why many companies are improving their order-picking tasks by using more efficient methods [5-7] and technologies [8, 9]. Since walking presents up to 50 % of the total picking time [4, 10], the logical way of improving this is to reduce or eliminate the unproductive walking, set-up, and searching time.

To improve efficiency in order picking operations, companies are experimenting increasingly with smart glasses [11], a kind of Head-Mounted Display (HMD). Powered by their own processor and battery, they collect data from a wireless network and project it onto a tiny screen incorporated into the glasses. From a user's perspective, the display looks like a full-sized display of text or graphic, overlaid on top of the "real world" scene viewed at the time. Workers benefit from hands-free access to computer-generated info, routeing to storage locations, eliminating the need to carry handheld scanners or written documents, thereby working conditions and productivity can be increased in parallel.

Despite the first pilot projects, technology is still developing. Theory [12] and practice [11] propose experiments with different products and applications before wider use in the warehouse. Some general recommendations presented in [13] can also be taken into account. A fundamental question is whether it could be harmful for the human eye to work a full day with smart glasses [14, 15].

## 2. Literature review

Systems using Head-Mounted Displays (HMDs) to support the order picking process are, in theory and practice, named Pick-by-vision systems. These systems are further divided according to (1) The ability to track user movements, and (2) The way of displaying information to a user in two subgroups [16]:

- Pick-by-vision (2D) systems (user position is not tracked, textual information in the form of a list of items or images is projected on the user's HMD);
- Pick-by-vision (AR) systems (use tracking, and make explicit use of Augmented Reality (AR) in a way that virtual objects are overlaid on the real-world environment and consist of the following parts [17]: Display, computer, input device and tracking system).

Smart glasses, also named as data glasses, are an example of HMD. In this paper, we focus on the possible harmful effects of the use of smart glasses.

Peli [18] researched Visual issues in the use of HMD already in 1990. Findings that base on a max of 20 minutes of tests in a laboratory environment, did not reveal any potential harmful effects, except not recommending use while driving. Six years later, Peli [12] wrote that the concerns about possible harmful effects are accompanying the introduction of almost any new wide-use-technology and HMD are not an exception. He concluded that it appears to be most appropriate to test each system separately. This will enable the developer to determine for each design that comfortable and safe use, by the target population and the intended use, is achievable.

Two years later, Peli [19] performed test sessions and measured the following visual parameters: (1) Accommodative status by refraction (auto refractor); (2) Binocular (OU) visual acuity at distance (6 m) with habitual correction; (3) Fixation disparity (lateral and vertical) at distance; (4) Stereoacuity at near distance (40 cm); (5) Phoria (lateral and vertical) at distance, and near (cover-test with prism-bar and Von-Graefe in the phoropter); (6) Vergence (horizontal and vertical) at distance and near; (7) Accommodative reserve by Fuse Cross Cylinder (FCC); (8) Convergence reserve, measured by negative and positive relative accommodation (NRA and PRA, respectively); (9) TBU time; (10) Contrast sensitivity at distance (OU) at three spatial frequencies (2, 3, and 6 c/deg). The reported data show no harmful or statistically significant changes to the visual system associated with use of the i-glasses HMD, in either *stereo* or *mono* mode, relative to the use of a desktop CRT display.

Researchers often use NASA Task Load Index (NASA-TLX), a subjective, multidimensional assessment tool that rates perceived workload in order to assess pick-by-vision systems or other aspects of performance. It has been cited in over 4,400 studies, highlighting the influence the NASA-TLX has had in human factors' research [20]. Regarding user strain, Schwerdtfeger *et al.* [16] found that even though they have uncomfortable HMD headbands, a backpack to carry, and non-addressable display focal planes, their system did not cause a higher general user strain than the conventional paper list. Nevertheless, the discomfort questionnaire shows that improvements of the display devices are necessary to reduce the potential for headaches.

After 2010, smart glasses have been adopted as a safe enough technology for use in pilot projects. Since then, we have begun to encounter more research that explores different technical designs and combinations of different technologies to achieve optimum work results. Ergonomic aspects are still in the background of productivity studies.

In 2014, the number of publications on smart glasses and HMD topics started to increase markedly, according to the World of Science (WoS), from 11 in 2014 to 46 in 2018. From 168 published papers, 44.6 % are from the Computer Science research area, 39.8 % from Engineering and 16.07 % from Ophthalmology.

With the rapid development of mobile Head-Mounted Display (HMD), the problem of visual discomfort and visual fatigue caused by watching Virtual Reality (VR) contents became a crucial concern for consumers and manufacturers, especially given that the casing of a mobile HMD keeps the phone at a specified distance from the lenses that is close to the eyes [21]. In this regard, Jungmin *et al.* [21] conducted both subjective and objective measures to evaluate visual discomfort and visual fatigue caused by watching HMD and smartphones. Participants answered a Simulator Sickness Questionnaire (SSQ) and went through optometric tests that measure tear break-up time, spherical equivalent, and contrast sensitivity. Experimental results show that HMD causes more eye dryness compared to smartphones.

Klein-Theyer *et al.* [14] agree that the implementation of near-eye display devices is promising for the future of order picking systems and in various other workplace scenarios. However, in 2017, the workload associated with the use of a visually guided commissioning system had not yet been investigated. Authors investigate ocular comfort, ocular surface and tear function parameters before and after the completion of a task using either a visual- or a voice-guided picking solution. Recent publications indicate that up to 90 % of computer users experience ocular discomfort after prolonged computer use, and approximately 10 % of visual display unit users have severe complaints [22-25]. The visual analogue scale values were increased significantly with the visual system when compared to the voice system, and with the visual system after the work session had finished (i.e., pre- vs post-task), which suggests that visually guided picking solutions may influence ocular comfort adversely. The analysis of the objective data revealed a significant decrease in the tear break-up time values of the right eyes, and a minor decrease in the values of the left eyes, following the completion of the visually guided picking task. The tear break-up time values for the voice-guided condition remained stable (right eyes) or even increased (left eyes) after the work.

From a chronological review of scientific articles, we can conclude that researchers have only begun to study the impact of using HMD, or more precisely smart glasses, on people's vision. Researchers agree that smart glasses have a potential to be used more widely in manual order picking systems. Ophthalmologic studies are rare, and based mostly on short-term use of HMDs, less than an hour. Although most authors evaluate a pick-by-vision system with HMDs as competitive, productive and promising technology, which hold large potential in the future, questions linked to the effects of long-term use are still unanswered [15].

## 3. Materials and methods

We tested the effects of using Vuzix M300 Smart glasses on users' comfort during order picking activities in a testing warehouse environment at the Faculty of Mechanical Engineering, Maribor. The protocol of performed research is described below, and summarised in Fig. 1. 14 persons, mostly students, tested selected Head-Mounted Displays (HMD), owned by the company Špica International. The testing period lasted four hours. Before and after use of smart glasses several ophthalmologic tests (visual acuity, contrast sensitivity, visual field testing and colour test) were performed, therefore we got 28 measurements altogether.

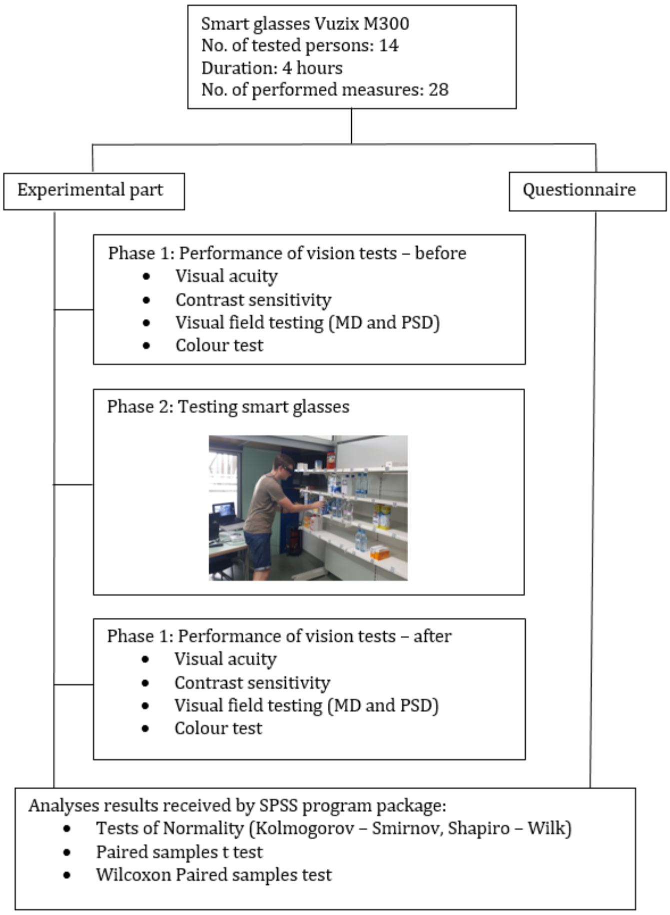

**Fig. 1** Experimental protocol – Testing Vuzix M300 smart glasses

### 3.1 Performed ophthalmologic tests

*Visual acuity*

Measurement of visual acuity is a sensitive test of the integrity of the visual system. It fulfils all standard criteria of a good screening test: Minimal cost or risk to the patient, measurement can be performed quickly and easily with little or no examiner training, there is a high prevalence of detectable abnormalities, and abnormalities are most often amenable to treatment. The goal in testing central visual acuity is to determine the best possible visual acuity in each eye. In most instances, either a standard printed Snellen eye chart is used, or a reading card such as, e.g. ETDRS chart (Early Treatment Diabetic Study). One eye at a time is tested with the fellow eye occluded.

In our study, visual acuity was measured with use of the Snellen table. It is less accurate and repeatable as an ETDRS chart. Thus, we decided to include the candidates who had the best corrected visual acuity of 0.7 or more. The best corrected visual acuity in emmetropic patients is 1.0. The reason for including a factor of 0.7 of visual acuity is also for better cooperation in the test of visual field (perimetry), and for excluding possible pathology which could impair the visual acuity. Visual acuity was measured separately for right and left eyes.

*Pelli Robson contrast sensitivity*

Contrast sensitivity was performed by using the Pelli-Robson table (Fig. 2) which is fast and reliable enough for our study. In the literature it is used as a factor connected with loss of Retinal Nerve Fibre Layer (RNFL), and, thus, with impairment of visual functions. We tested each eye separately and also binocularly. During the testing, we encouraged the tested subject to concentrate himself to say as much as possible. The normal result is a log value of 1.95 or 2.0. Values less than 1.8 could indicate improper contrast vision in bad visual conditions.

**Fig. 2** Pelli Robson table

*Visual field testing*

A visual field test is an eye examination that can detect dysfunction in central and peripheral vision, which may be caused by various medical conditions. Visual field testing can be performed clinically by keeping the subject's gaze fixed while presenting objects at various places within their visual field.

Visual field testing of 30 degrees of the central visual field was performed with a computer static perimetry full threshold algorithm using an OCTOPUS machine (Fig. 3) at standardised illumination parameters. 30 degree visual field testing could show possible scotomas (visual field defects) in the areas where the glasses were projected. For reliability of perimetry testing, the cooperation of the tested individual is very important. At a loss of fixation during the testing of more than 20 %, and false positive or negative below 15 %, the test result is inaccurate, and not reliable enough to say with 95 % possibility that scotoma actually exists. Together with visual acuity better than 0.7 and ability of tested individuals to be concentrated during the examination, makes the result more reliable regarding the new scotomas after the use of glasses.

*Ishihara colour test*

The colour vision testing was performed with use of Ishihara tables, which are used widely in clinical examination, and can indicate the presence of colour vision defects reliably, especially for results with more than 10 % of failures. The advantages using Ishihara tables is their ease of use and speed of performing, so the tested individual is not bored and losing his concentration. In the literature, the Hue 100 test is also performed mainly to quantify and to distinguish what kind of anomaly (protanomaly, deuteranomaly, and tritanomaly) is present in the tested individual. In our study, the colour vision was important, mainly to compare the results before and after the use of glasses.

**Fig. 3** Octopus perimeter (Source: mandarinoptomedic.com)

### 3.2 Statistical analyses

All statistical analyses were performed through the Statistical Package for Social Sciences (SPSS) version 25. Within the descriptive statistics, the mean, Standard Deviations and standard error mean were calculated for all measurements.

The population normality was verified by using Kolmogorov-Smirnov and Shapiro-Wilk tests. Differences between performed tests before and after have been verified by the *t*-test for paired samples, or the Wilcoxon signed rank test, depending on the distribution of changes. Since the data were not normally distributed in certain cases, we used the paired samples *t*-test for the normal and Wilcoxon test for the non-normal data within the group comparison. Additionally, effect sizes were calculated, to have a standardised measure of the size of the effect we observed, and to be able to compare results to other studies if they appeared.

In order to compare the results gathered with all performed ophthalmologic tests, the null hypothesis was stated that no changes are expected before and after use of smart glasses: $\mathrm{H_o} : \mu_{\text{test before}} = \mu_{\text{test after}}$

The values were considered statistically significant at $p \leq 0.05$.

# 4. Results and discussion

## 4.1 Visual acuity

Normal visual acuity for a healthy human is 1.0. It means that humans see clear optotypes with standard values at a defined distance (6 m). In our study (Table 1), the majority of included candidates had visual acuity more than 0.7 that we set as a limit value. Only three of the tested persons had visual acuity less than 0.7.

**Table 1** Visual acuity before and after using smart glasses

| No. of testee | *VARb* | *VARa* | *VALb* | *VALa* |
|---|---|---|---|---|
| 1 | 0.8 | 0.8 | 0.8 | 0.8 |
| 2 | 1.0 | 1.0 | 1.0 | 1.0 |
| 3 | 1.0 | 1.0 | 1.0 | 1.0 |
| 4 | 0.25 | 0.25 | 0.4 | 0.4 |
| 5 | 0.63 | 0.5 | 0.4 | 0.32 |
| 6 | 1.0 | 0.8 | 1.0 | 0.8 |
| 7 | 1.0 | 1.0 | 1.0 | 1.0 |
| 8 | 1.0 | 0.8 | 1.0 | 1.0 |
| 9 | 0.8 | 0.63 | 0.8 | 0.63 |
| 10 | 1.0 | 1.0 | 1.0 | 1.0 |
| 11 | 1.0 | 1.0 | 1.0 | 1.0 |
| 12 | 0.4 | 0.4 | 0.8 | 0.63 |
| 13 | 0.8 | 0.8 | 0.8 | 0.8 |
| 14 | 0.8 | 0.63 | 0.8 | 0.63 |

*Note: VARb* – Visual Acuity, right eye, before; *VARa* – Visual Acuity, right eye, after; *VALb* – Visual Acuity, left eye, before; *VALa* – Visual Acuity, left eye, after

## 4.2 Pelli Robson contrast sensitivity

The lowest contrast at which a tested person can read three letters of the same group on a Pelli Robson table determines the logarithm evaluation of contrast sensitivity (Table 2).

**Table 2** Contrast sensitivity before and after using smart glasses

| No. of testee | *CSRb* | *CSRa* | *CSLb* | *CSLa* | *CSbothb* | *CSbotha* |
|---|---|---|---|---|---|---|
| 1 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 2 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 3 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 4 | 1.50 | 1.50 | 1.50 | 1.50 | 1.65 | 1.65 |
| 5 | 1.65 | 1.65 | 1.50 | 1.50 | 1.65 | 1.65 |
| 6 | 1.65 | 1.65 | 1.65 | 1.50 | 1.65 | 1.65 |
| 7 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 8 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 9 | 1.65 | 1.35 | 1.65 | 1.35 | 1.80 | 1.65 |
| 10 | 1.65 | 1.65 | 1.65 | 1.50 | 1.95 | 1.95 |
| 11 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 12 | 1.65 | 1.50 | 1.65 | 1.50 | 1.80 | 1.50 |
| 13 | 1.65 | 1.65 | 1.65 | 1.65 | 1.80 | 1.80 |
| 14 | 1.50 | 1.50 | 1.50 | 1.50 | 1.80 | 1.80 |

*Note: CSRb* – Contrast sensitivity, right eye, before; *CSRa* – Contrast sensitivity, right eye, after; *CSLb* – Contrast sensitivity, left eye, before; *CSLa* – Contrast sensitivity, left eye, after; *CSbothb* – Contrast sensitivity, both eyes, before; *CSbotha* – Contrast sensitivity, both eyes, after

Value 2.0 presents normal contrast sensitivity, or 100 %. Values less than 1.5 show visual handicap, and values less than 1.0 greater visual impairment. Results in Table 2 show that all tested candidates have contrast sensitivity equal to or greater than 1.5, which means that they can be treated as persons with normal contrast sensitivity.

### 4.3 Visual field testing

For visual field testing we used Octopus perimeter. First measurements were performed with the programme Treshold 30-2. The measurement was performed only on the right eye (this is the eye where the smart glasses display was). To examine changes in the visual field two parameters were used: *MD* (Mean Deviation) and *PSD* (Pattern Standard Deviation), which is used for quantifying the differences in sensitivity in the visual field. The purpose of our study here was to see if the difference of *MD* and *PSD* was significant.

*Mean deviation*

The average of deviations across all test locations is referred to as the Mean Deviation (*MD*). Subjects who are able to see dimmer stimuli than others of similar age and race, will have positive values for their *MD*, while subjects who require brighter stimuli will have negative *MD* values [26]. *MD* values for reliable tests typically range from +2 dB to −30 dB.

Results in the Table 3 show that the mean value of Mean Deviation before work with smart glasses was −2.54, and after 4-hours of using smart glasses −2.67. It means that the value after 4-hours working with smart glasses was lower by 5 % (Δ = 0.13).

*Pattern standard deviation*

Visual field loss in glaucoma is frequently non-uniform, and, thus, a measure which quantifies irregularities is desirable [26]. Pattern Standard Deviation (*PSD*) measures irregularity by summing the absolute value of the difference between the threshold value for each point and the average visual field sensitivity at each point (equal to the normal value for each point + the *MD*). Visual fields with the age-normal sensitivity at each point will have a *PSD* of zero, as will visual fields in which each point is depressed uniformly from the age-normal value. Thus, the largest *PSD* will be registered for focal, deep visual field defects. Near normal and severely damaged visual fields will both have low *PSD* [26]. Results of our tests are presented in Table 3.

**Table 3** *MD* and *PSD* before and after using smart glasses

| No. of testee | *MDb* | *MDa* | *PSDb* | *PSDa* |
|---|---|---|---|---|
| 1 | -2.25 | -2.16 | 3.71 | 2.47 |
| 2 | -0.71 | -1.05 | 2.01 | 2.99 |
| 3 | -4.80 | -3.09 | 3.24 | 2.54 |
| 4 | -5.21 | -3.55 | 2.42 | 2.32 |
| 5 | 0.29 | -2.87 | 3.10 | 3.19 |
| 6 | -5.27 | -4.48 | 3.45 | 3.02 |
| 7 | -1.68 | -2.77 | 2.37 | 2.33 |
| 8 | -1.45 | -3.99 | 1.97 | 2.18 |
| 9 | -0.69 | -2.63 | 1.79 | 2.61 |
| 10 | -1.39 | -1.07 | 2.09 | 2.37 |
| 11 | -3.32 | -3.79 | 2.15 | 3.15 |
| 12 | -1.48 | -2.29 | 2.34 | 1.99 |
| 13 | -1.99 | -3.15 | 2.09 | 3.21 |
| 14 | -5.64 | -0.49 | 3.62 | 2.34 |

*Note: MDb* – Mean Deviation, before; *MDa* – Mean Deviation, after; *PSDb* – Pattern Standard Deviation, before; *PSDa* – Pattern Standard Deviation, after

### 4.4 Ishihara colour test

We used 15 colour plates of the Ishihara test (numbers, including the test plates) with 12 or more correct indicating normal colour vision. Again, we wanted to measure the difference in colour vision perception before and after the use of smart glasses. In our result, there was some discrepancy regarding the individual possible mild colour anomaly, and regarding the individual concentration during the test. Thus, the majority of tested persons had normal colour vision, except two individuals where an impairment in colour vision was indicated (Table 4).

We also studied the possible scotomas in the area of the visual field where the smart glasses had a projection. In some cases, scotomas were present after the use of smart glasses. That might indicate that glasses can cause some vision impairment after use, projecting in the same quadrant, lowering the sensitivity in that area of the visual field (Table 4).

The Treshold 30-2 programme was performed on the right eye, which is the eye where the display was. If we found a scotoma, we marked it as 1, and if the scotoma was not present, we marked it as 0. Results of our test show that before using smart glasses no tested persons had scotomas, but after using smart glasses 6 persons had it. It presents 43 % of those tested, therefore, we can justify that the presence of scotoma in the right eye can be the result of load caused by using smart glasses. To verify the results gained with the Treshold 30-2 programme we also performed the Driver's licence test for both eyes. According to the Driver's license test, we found two scotomas after using smart glasses, which is less than with the Treshold 30-2 programme. This could also be caused by the complexity of the performed research and the duration. Treshold 30-2 lasts 15 minutes and the Driver's license test only 4 minutes. In both tests the concentration of the tested persons is very important, and can influence the results.

**Table 4** Colour test and visual field test before and after using smart glasses

| | | | Treshold 30-2 | | Driver's licence | |
|---|---|---|---|---|---|---|
| No. of testee | *CTb* | *CTa* | *SCOb* | *SCOa* | *SCOb* | *SCOa* |
| 1 | 15 | 15 | 0 | 0 | 0 | 0 |
| 2 | 3 | 3 | 0 | 0 | 0 | 0 |
| 3 | 15 | 15 | 0 | 0 | 0 | 0 |
| 4 | 15 | 15 | 0 | 1 | 0 | 0 |
| 5 | 15 | 15 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 0 | 1 | 0 | 1 |
| 7 | 15 | 15 | 0 | 0 | 0 | 0 |
| 8 | 15 | 15 | 0 | 1 | 0 | 0 |
| 9 | 15 | 15 | 0 | 0 | 0 | 0 |
| 10 | 15 | 15 | 0 | 1 | 0 | 0 |
| 11 | 15 | 15 | 0 | 1 | 0 | 0 |
| 12 | 15 | 15 | 0 | 0 | 0 | 0 |
| 13 | 15 | 15 | 0 | 1 | 0 | 1 |
| 14 | 15 | 15 | 0 | 0 | 0 | 0 |

*Note: CTb* – Colour test, before; *CTa* – Colour test, after; *SCOb* – Scotoma, before; *SCOa* – Scotoma, after

### 4.5 Statistical analysis results

Results of statistical analysis for all the performed analyses are summarised in Table 5. Statistically significant differences with $p \leq 0.05$ are in bold.

**Table 5** Results of descriptive statistics, *t*-test for paired samples and Wilcoxon test

| | Before | | | After | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | *SD* | St. Err. Mean | Mean | *SD* | St. Err. Mean | *t*-test *p* | Wilcoxon test *p* | Effect size |
| *VAR* | 0.820 | 0.242 | 0.064 | 0.757 | 0.245 | 0.065 | **0.020** | **0.041** | **-0.38** |
| *VAL* | 0.842 | 0.210 | 0.056 | 0.786 | 0.234 | 0.062 | **0.024** | **0.039** | **-0.39** |
| *CSR* | 1.628 | 0.054 | 0.014 | 1.596 | 0.095 | 0.025 | 0.189 | 0.18 | - |
| *CSL* | 1.617 | 0.063 | 0.017 | 1.564 | 0.096 | 0.025 | 0.055 | 0.059 | - |
| *CS* | 1.778 | 0.080 | 0.021 | 1.746 | 0.111 | 0.029 | 0.189 | 0.18 | - |
| *CT* | 13.143 | 4.737 | 1.266 | 13.143 | 4.737 | 1.266 | - | 1.00 | - |
| *MD* | -2.542 | 1.950 | 0.521 | -2.670 | 1.171 | 0.313 | 0.822 | 0.470 | - |
| *PSD* | 2.596 | 0.675 | 0.180 | 2.622 | 0.409 | 0.109 | 0.904 | 0.975 | - |
| *ST* | 0 | 0 | 0 | 0.428 | 0.513 | 0.137 | **0.008** | **0.014** | **0.45** |

*Note: VAR* – Visual Acuity, right eye; *VAL* – Visual Acuity, left eye; *CSR* – Contrast sensitivity, right eye; *CSL* – Contrast sensitivity, left eye; *CS* – Contrast sensitivity of both eyes; *CT* – Colour test; *MD* – Mean Deviation; *PSD* – Pattern Standard Deviation; *ST* – Scotoma Threshold 30-2

Results of visual acuity for the right eye show that the mean value before work with smart glasses was 0.82, and after 0.76. Visual acuity was lower after using smart glasses for Δ = 0.062 (7.6 %). It means that tested persons' sight was weaker after use of smart glasses than before. Since the results of both tests (*t* test and Wilcoxon test) show significant difference, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ should be disproved. The effect size is $r = -0.38$. This represents a medium to large change in visual acuity for the right eye.

For the left eye, the results of visual acuity are similar as for the right eye, but there are slight differences. The mean value before work with smart glasses was 0.84, and after 0.76. Visual acuity after using smart glasses was also lower by Δ = 0.056 (6.7 %), meaning that tested persons' sight was weaker after use of smart glasses. According to the results of the *t* and Wilcoxon tests, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ should be disproved. The effect size is $r = -0.39$. This represents a medium to large change in visual acuity for the left eye.

Comparison between right and left eye show that visual acuity of the right eye reduced by 7.6 %, and 6.7 % for the left eye. All tested persons had the visual display of the smart glasses in front of their right eye, therefore the weaker sight on the right eye could be caused by using smart glasses.

The mean value of contrast sensitivity for the right eye before work with smart glasses was 1.63, and after 1.60. Contrast sensitivity was lower after using smart glasses by Δ = 0.03 (2 %). It means that the tested persons' contrast sensitivity was weaker after use of smart glasses than before. But the results of both tests (*t* and Wilcoxon test) do not show significant difference; *p* values are greater than 0.05, therefore the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ cannot be disproved.

A similar situation is evidenced for the left eye, where the mean value of contrast sensitivity changed from 1.62 to 1.56, Δ = 0.05 (3 %), meaning that the tested persons' contrast sensitivity was weaker after the use of smart glasses than before. Results of both tests (t and Wilcoxon test) show no significant difference, therefore, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ cannot be disproved.

The mean value of contrast sensitivity for both eyes changed from 1.78 to 1.75, which means that contrast sensitivity was lower after using smart glasses by Δ = 0.03 (1.8 %). Tested persons perceived lower contrast sensitivity after using smart glasses, but, since the measured value was not lower than 1.5, use of smart glasses is not harmful for eye contrast sensitivity [27]. The mean value of perceiving contrast sensitivity was binocularly better than monocular, which is also verified with other studies [28].

Results of both tests (*t* and Wilcoxon test) gave us *p* values greater than 0.05, therefore, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ cannot be disproved.

The mean value of the Mean Deviation test (*MD* test) of visual field is -2.54 before using smart glasses and -2.67 after. The value after 4-hours use of smart glasses was lower by Δ = 0.13 (5 %). Regarding the values of the *t* and Wilcoxon tests, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ cannot be disproved.

Our results were lower than the normal range before testing, which can be influenced by the patient's psychological state, concentration and cooperation during the test. We must be aware of the state when the tested individual performs the first test of the visual field. Besides that, our results statistically did not show a significant difference before and after the test.

The mean value of the Pattern Standard Deviation test (*PSD* test) before work with smart glasses was 2.6, and after 2.62. The tested value after 4-hours use of smart glasses was slightly higher by Δ = 0.03, or less than 1 %. Regarding the values of the *t* and Wilcoxon tests, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ cannot be disproved.

High values of PSD represent the scotomas [26]. The Treshold 30-2 Programme confirmed the increased level of scotoma in the right eye, but the Driver's license test gave us a lower level of scotomas. Even the second test couldn't confirm the results of Treshold 30-2 totally, so it can be concluded that the presence of scotoma in the right eye can be the result of load caused by using smart glasses. The results of the *t* and Wilcoxon tests had *p* values less than 0.05, therefore, the null hypothesis $H_o : \mu_{\text{VARbefore}} = \mu_{\text{VARafter}}$ should be disproved. The effect size is $r = 0.45$. This represents a medium to large change in the level of scotoma.

The results of the performed ophthalmologic tests (visual acuity, contrast sensitivity, visual field testing and colour test), show that there are some statistically significant differences between tests results performed before and after use of smart glasses that cannot be overlooked. The difference between the results of visual acuity for the left and right eyes is small, but, in both cases, the visual acuity is lower after use of smart glasses. The contrast sensitivity and colour test did not show any statistically significant differences, but the additional test of the visual field did.

From the results of the visual field test we found out that none of the tested individuals had the scotoma (dysfunction in central and peripheral vision) in the right eye (inferior quadrant where the projection of smart glasses was performed) before using smart glasses. After the test, scotomas were present in the same quadrant in 43 % of cases. This might indicate that use of smart glasses for four hours during work can cause scotomas and, thus, impairment in the visual field and vision.

The percentage of scotomas in the right eye after using smart glasses is high, therefore, we tried to find out if there are any other influence parameters that should be considered. It is known that perimetry is a subjective testing, affected mainly by the psychological state of the individual and by their cooperation and concentration. Therefore, this might be the influential factor. We also did only one measure before and after per tested person, because the test is time consuming, and it is known from the literature [26] that perimetry gives the best results usually at a second testing, when the tested person is more familiar with the procedure. The size of the tested group was relatively small, but even though it was performed as a pilot test, results were somehow surprisingly high. We also did the additional Driver's Licence test, which is faster and, thus, less affected by the motivation of tested individual. In the Driver's licence test the presence of scotomas was lower, but they were still present in 14 % of cases.

## 5. Conclusion

With the intent to create added value, warehouses must be aligned with modern industry trends, as well as with novel business approaches enabled by modern forms of organisation and ICT [29-31].

Systems using Head-Mounted Displays (HMDs) are still developing, and there is a lack of research concerning human comfort during a full work day with this kind of equipment. In our research, we tried to answer the question whether use of smart glasses could be harmful for the human eye or not during four-hour use.

Based on the results of all the performed tests, we can conclude that use of smart glasses has an effect on the user's vision, and, therefore, further research would be of benefit before implementing it in warehouses as a part of everyday equipment for workers. During our research, a number of questions appeared that could be addressed in the future:

- Visual acuity during the workday; Does normal visual acuity of a healthy human change during the day?
- Appearance of scotoma; we researched the presence of scotomas only in the right eye and, therefore, we couldn't compare the results with results of the left eye.
- Appearance of scotoma during the day.
- Appearance of scotoma regarding the kind of work; additional research would be of benefit if certain kinds of work could be identified that have greater prevalence for scotoma formation.
- Identical research could be performed, but with the projection of smart glasses in the left inferior quadrant.
- Does the appearance of scotoma affect a driver's abilities?

Our pilot test was performed with limited resources on 14 persons. All tests were performed twice, before and after working with smart glasses, therefore, our conclusions based on 28 measures. In the future, rigorous, empirically based research, performed on a greater number of tested persons, could help to clear up doubts that still exist concerning the presented topic.

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