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Glare as a specific factor in the working environment

***Abstract.** The article presents elaborated criteria of risk assessment related to glare and recommendations of prevention measures on the base of carried out studies on work stations, where existed special hazard of occupational accidents due to existing glare. The results of study on glare on non-stationary work places in repair shipyard showed that one of indirect reasons of accidents was disability or blinding glare. These results were used to elaborate the criteria of risk assessment related to glare on non-stationary workplaces.*

***Streszczenie**. Artykuł przedstawia opracowane kryteria oceny ryzyka związanego z olśnieniem oraz zalecenia prewencyjne na podstawie przeprowadzonych badań na stanowiskach pracy, na których występowało szczególne zagrożenie wypadkowe na skutek olśnienia. Wyniki badań na niestacjonarnych stanowiskach pracy w stoczni remontowej wykazały, że jedną z pośrednich przyczyn wypadków było olśnienie przeszkadzające lub oślepiające. Wyniki te posłużyły do opracowania kryteriów oceny ryzyka związanego z olśnieniem na niestacjonarnych stanowiskach pracy. (**Olśnienie jak szczególny czynnik ryzyka w środowisku pracy**).*

Keywords: glare, non-stationary workplaces, glare sensitivity, occupational risk assessment criteria
Słowa kluczowe: olśnienie, niestacjonarne stanowiska pracy, wrażliwość na olśnienie, kryteria oceny ryzyka zawodowego .

Introduction

Glare is that condition of vision in which there is discomfort, a reduction in the ability to see objects – both due to an unsuitable distribution, range of luminance, or to extreme contrasts in space or time [4]. There are three main types of glare [2]: discomfort glare, disability glare and blinding glare. Discomfort glare causes discomfort without necessarily impairing the vision of objects and disability glare impairs the vision of objects without necessarily causing discomfort [4]. Blinding glare impairs the vision in a way that for the short but noticeable time after exposure to a glare source nothing can be seen. All three types of glare occur in the working environment and should be taken into consideration during occupational risk assessment because they can affect occupational accident hazards and cause nuisance in visual work, which, adversely affect visual fatigue and work efficiency. Therefore, glare is mentioned as one of the indirect reasons of occupational accidents [1, 13, 14]. Depending on the glare type – discomfort, disability, or blinding – the hazard is different and each is related with its own occupational risk.

According to the law, the employer is obligated to carry out risk assessment arising from all hazardous agents. In interior areas when the work is performed temporarily and local lighting is used, problems with disability and even blinding glare can often occur. The local luminaires are positioned accidentally by workers, often in the near to central field of view, and the very bright sources induce the glare. The most often local lighting luminaires are equipped with: tungsten filament lamps, metal halide lamps, and high pressure sodium. When performing the work task, a brief accidental glance on the very bright uncovered part of a glare source could cause disability or even the blinding glare. The level of risk related to each glare type is different, but there is a lack of criteria, which would allow to estimate the type of glare and thus its related risk.

This article presents criteria for glare type assessment on non-stationery workplaces, which could be easily implemented for measurements and occupational risk assessment. Some prevention measures to minimize accident hazards related to glare on these types of workstations are also proposed.

Criteria of glare type assessment for non-stationary workplaces

The lighting measurements were carried out on these non-stationary workplaces where workers were exposed to exceptional glare. It concerned the workstations where the following activities were performed: assembly of different elements, welding, grinding, sanding, painting and flame melting. The bright luminaires were usually placed on dark background. The low reflectances of main surfaces (0,1 ÷ 0,3) and low levels of illuminance on the working plane (7 lx ÷ 287 lx) caused a low luminance environment to which the eyes of workers were adapted. The glare from very bright lamps installed in the local luminaires (measured maximum luminance up to 700 000 cd/m^2) could have caused disability glare and sometimes even blinding glare. The background luminances were in the range of 7 ÷ 90 cd/m^2.

Disability glare depends mainly on retinal illuminance [7, 16]. If the retinal illuminance is high, it could cause disability and even blinding glare. To estimate retinal illuminance E_{retina} (in td) we need to know the luminance of the observed light source (L_{source} in cd/m^2) and the pupil diameter (S, in mm^2) [8, 9, 10]:

$$E_{retina} = L_{source} \cdot S \tag{1}$$

The pupil diameter changes with the amount of light falling on it and also (decreases) with age. Change in pupil diameter is response to retinal illumination. For example, with the reaction of 9 a cd/m^2 luminance light stimulus the pupil diameter reaches 7,2 mm for 20 year-olds and 5 mm for 70 year-olds; however, with a luminance of 4 400 cd/m^2 the pupil diameter reaches respectively: 3,8 mm and 3 mm. It is widely accepted that observing sources of high luminance, above 10 000 cd/m^2, results in the pupil diameter contraction of 3 mm (regardless of age) whereas the pupil diameter adapted to darkness is 7 mm [8, 9]. It is accepted that photopigment in the cones is fully bleached at the retinal illuminance of about 10 mln td. [8, 9, 10] Based on these findings, it was assumed that, blinding glare occurs whenever the retina is exposed to a high luminance light source causing receptors to be „Fully Bleached” During this time, as long as the pigment doesn't regenerate, the perception abilities are inhibited. Exposing the eye to a high luminance stimulus causes the pupil constriction that occurs after a brief latency period from the moment of its exposition (i.e. latency of pupillary reflex to light stimulation), on average agreed to be about 0,3 s [7]. Experiments taken at that time prove that that this latency period depends upon the luminance of the glare source and can range from a few tenths to a few hundredths of a millisecond [3]. In order to evaluate illuminance on the eye's retina for light sources with varying luminance, the formula (1) above was utilized, and the results are presented in table 1. The cells in table 1 in grey color corresponds to the full bleach of photopigment. The data presents retinal illuminance with varying pupil diameters for specific luminance taking into account the following occurrences:

- pupils could be wider than expected when compared to the level of retinal illuminance; this can be caused by the consumption of pharmaceutical substances, built up emotions, or sicknesses that limit pupil constriction,
- pupils could be less widened than expected when compared to the level of retinal illuminance; this can be caused by the consumption of pharmaceutical substances or sicknesses that cause excessive pupil constriction.

When establishing the criteria for glare type assessment, it was accepted that in the first phase of exposition to the glare source – equaling the latency period of pupillary reflex – on the retina can present a higher level of illuminance, which depends on the background luminance (i.e. luminance controlling the adaptation level of the observer's eye) before the glare. This illuminance level corresponds to the pupil diameter before its constriction. For example, the pupil latency period ranging from a few tenths of a millisecond for sources of luminance above 4400 cd/m^2 [3, 12]. This amount of time can be enough to cause different types of glare. When establishing the criteria for glare type assessment it was accepted that directly before the glare occurred the pupil could be widened to:

- 7 mm when $L_{background}$ ≤ 10 cd/m^2
- 6 mm when 10 cd/m^2 < $L_{background}$ < 100 cd/m^2,
- 5 mm when 100 cd/m^2 ≤ $L_{background}$ < 1000 cd/m^2
- 4 mm when 1000 cd/m^2 ≤ $L_{background}$ < 10 000 cd/m^2,
- 3 mm when $L_{background}$ ≥ 10 000 cd/m^2

It was further agreed upon that discomfort glare doesn't occur if the source luminance doesn't exceed 600 cd/m^2. This is because cone photopigment bleaching hasn't yet taken place at the luminance values below 600 cd/m^2, and adaptation involves neural process. Furthermore, it is generally agreed that source luminance must be greater than 500 ÷ 700 cd/m^2 for discomfort glare to exist [4].

Taking into consideration the effect of an eye's illuminance adaptation on the pupil size as well as the latency of the pupillary reflex period, two parameters capable of being measured at the workplace were taken into account when assessing glare type criteria: source luminance and background luminance, to which the eye is already adapted to. During the measurement, the worst conditions were assumed, i.e. such where the worker is exposed to the greatest glare. Other parameters that influence the sensation of glare (for example the location of the source related to the location of the observer as well as its size) were neglected due to the fact that when assessing glare type criteria only the worst conditions should be taken into consideration. Taking into consideration the above mentioned assumptions, the proposed criteria of glare type assessment and related occupational risk are presented in table 2.

Table 1. Retinal illuminace for different source luminances and pupil diameter

Lp	Source luminance cd/m^2	Retinal illuminance in trolands, for different pupil diameter				
		3 mm	4 mm	5 mm	6 mm	7 mm
1	10	71	126	196**	283**	385**
2	100	706	1 256	1 962	2 826	3 846
3	1 000	7 065	12 560	19 625	28 260	38 460
4	4 400	31 086**	55 264**	85 467	124 344	169 224
5	10 000***	70 650	125 600	196 250	282 600	384 600
6	260 000	1 836 900	3 265 600	5 102 500	7 347 600	10 000 000*
7	353 860	2 500 021	4 444 482	6 944 503	10 000 000*	-
8	509 554	3 600 000	6 400 000	10 000 000*	-	-
9	796 178	5 625 000	10 000 000*	-	-	
10	1 415 428	10 000 000*	-	-	-	-

* „full bleach" of photopigment in cones - blinding glare
** age dependent pupil diameter for particular source luminance [11, 12]
*** 3 mm pupil diameter, regardless of age; bigger diameters are possible when iris constriction is limited

Table 2. Criteria of glare type assessment on non-stationary workplaces

Source luminance cd/m^2	Background luminance, cd/m^2				
	< 10	10 ÷ 100	100 ÷ 1000	1000 ÷10 000	> 10 000
600 ÷ 10 000	Dicomfort glare (low risk)				-
10 000 ÷ 260 000	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)
> 260 000	Blinding glare (high risk)	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)
> 350 000	Blinding glare (high risk)	Blinding glare (high risk)	Disability glare (medium risk)	Disability glare (medium risk)	Disability glare (medium risk)
> 500 000	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)	Disability glare (medium risk)	Disability glare (medium risk)
> 800 000	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)	Disability glare (medium risk)
> 1 400 000	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)	Blinding glare (high risk)

Sensitivity to glare examinations

Occupational risk assessment related to glare in the workplace where there exists exceptional glare hazard is the most relevant in the basis for finding precautions that would limit such a risk. In many situations it won't be possible to use different luminaires or to position them differently in order to eliminate glare, like for example at repairing sites in dimensional restricting spaces of a ship. To minimize the risk of accidents related to glare, it seems reasonable to check the mesopic sensitivity to glare of candidates for work places where exceptional glare exists, similarly to tested professional driving candidates. In order to check if it is necessary to take these safety precautions, glare sensitivity examinations were done on repair shipyard and office workers, occupations which are at exceptional risk to glare and thus served as the control group.

The examinations were carried out using apparatus MESOTEST II (OCULUS, Germany). The standard assessment method used for professional drivers was applied [5, 6]. The presented Landolt's rings were of four different contrast (ring - background): 1:23, 1:5, 1:2,7, 1:2.

The exposed to glare group (shipyard workers) consisted of 42 workers (mean age 36,5 years, range 22-55 years) and control group (office workers) – 30 workers (mean age 37,7 years, range 23 – 64 years).

Results of sensitivity to glare under mesopic conditions examinations showed that together with lower contrast of the ring on the background the tendency of lower number of correctly recognized rings (the location of gap in the ring) was observed in both groups. The lowest number of correctly recognized rings were found for the test of the lowest ring contrast: 1:2 and for this test statistical significant difference between both groups were found (Mann-Whiteney U = 51,5, Z = 6,69, p < 0,001). It means that exposed to glare group had significantly lower sensitivity to glare comparing to control group at the lowest contrast.

Results on glare sensitivity examinations indicate a statistically lower sensitivity to glare among the group of workers exceptionally at risk during their work about glare than among the control group – office workers. Further research indicated that the group of workers at risk to glare identified the presented optotypes significantly faster than the test results collected from the control group**.** Taking onto account that sensitivity to glare were smaller in exposed to disability and even blinding glare group comparing to office workers which are at the most exposed to discomfort glare it could be concluded that work performed in conditions of disability or blinding glare presence made workers more resistant on glare in some way or they just have less sensitivity to glare.

Summary

On non-stationary workplaces where temporary lighting is used, maximum luminance of the glare source as well as the background luminance, which controls the adaptation level of the eyes, should be measured and then used for occupational risk assessment. Measurements should be taken for the worst visual conditions, when the exposure to glare for the workers is the greatest. Accepting in the worked out criteria only two parameters: luminance source and luminance background, which is capable of being measured in the workplace, enables identification of risk related to glare. If a moderate or high risk is detected then appropriate procedures should take place in order to limit such risk, especially:

- temporary workplaces should be lighted with the luminaires that limit glare hazard, made specifically for those kinds of jobs and satisfying all safety precautions related to lighting of the given site,
- employees as well as employers should be trained safety and correct ways of lighting temporary workplaces so glare arising from luminaires are eliminated, and they should also make sure of a required level of illuminance on the workplace area and communications zone.

However workers hired for these workplaces should be marked with a small sensitivity to glare. Due to this case it is recommended that, like in the case of testing proffesional driving candidates, preliminary medical examinations should be more developed including personal sensitivity to glare tests. Candidates who don't recognize 60% of the presented optotypes shouldn't be hired for these places of work.

Through the employers' practical implementation of this worked out criteria for risk assessment related to glare in the workplace as well as recommendation of accident preventive guidelines, occupational risk related to this factor may be limited as well as eye strain and visual fatigue

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