Humanities and Social Sciences **2020**
HSS, vol. XXV, 27 (4/2020), p. 39-49 **October-December**

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THE ISSUE OF ROAD VISIBILITY AND ROAD TRAFFIC SAFETY

One of the most difficult problems faced by drivers at night is road visibility and difficulty in seeing obstacles in a timely manner. Many night-time accidents occur on roads with no artificial lighting, especially outside built-up areas. In 2014, in order to improve road safety, a provision for the obligatory use of reflective elements by pedestrians outside built-up areas at night was introduced. However, the exact parameters of these reflective elements (in particular the color, size and location) were not specified, which may have an impact on pedestrian safety.

This article compares a car driver's range of visibility when pedestrians are equipped with different colors of a reflective element, examining the influence of different colors on safety. The analysis shows that, despite the similar technical properties of the same reflective elements, their color contributed to the improvement of visibility, and thus road safety. An experiment conducted in real road conditions testing yellow and orange reflective elements proved that the yellow reflective element significantly improved the range of the driver's perception.

Keywords: road traffic safety, pedestrian, driver, traffic accident

1. INTRODUCTION

The current level of knowledge of road traffic organization shows that a change in visibility leads to a change in the level of traffic safety. This is related to the characteristic features of seeing and observing by both, the driver and other road users, especially pedestrians, as unprotected road users. These parameters can be properly controlled with a view to improving road safety, and thus making the appropriate decision related to increasing the visibility of road users. The majority of people travelling on the road at night do not realize how much visibility the driver has after dark. If the road conditions force the driver to move with the dipped headlights on, the headlamps can illuminate the road ahead of the vehicle to a distance of only 40 m. The pedestrian, on the other hand, is visible from an even shorter distance, because the light beam must illuminate him about 25–30 cm measured from the road surface to make him visible to the driver, which means that in fact the distance from seeing the pedestrian is much shorter (about 20–25 m).

Due to the uneven value of luminance, different colors, or different intensity of lighting directed at road users and road infrastructure, the vehicle driver is usually not aware of the

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significant differences in perception of objects appearing on the road, and thus his reaction and adaptation of the way of driving towards these obstacles (Zielinkiewicz, 2013). The so-called unprotected road users (e.g. pedestrians, cyclists, users of personal transport devices, such as roller skates, skateboards, scooters, etc.) who do not have protection in the form of a vehicle body, and who, in contact with a speeding vehicle, usually have little or no chance (Podgórska, Rajchel, 2019).

There have been identified three main problems in terms of road safety at night (Fors, Lundkvist, 2009):

- light discomfort resulting from glare phenomenon or insufficient lighting;
- problems with correct distance estimation;
- not seeing other road users or obstacles in the immediate vicinity of the road;
- weakening of concentration associated with the increased role of fatigue.

Provisions regarding the improvement of visibility on the road were introduced into the Polish legal system on July 26, 2014 by the Act of July 26, 2013 amending the Road Traffic Act (The Act of July 26, 2013). Pursuant to Article 11 (4a) of the Act of June 20, 1997, Road Traffic Law (The Act of June 20, 1997), "A pedestrian walking on the road, after dusk, outside built-up areas, is obliged to use reflective elements in a manner visible to other road users, unless he is travelling on a road which is exclusively intended for pedestrians or on the sidewalk. This provision, in accordance with Article 11 (5) of this Act, "does not apply in the residential area where the pedestrian uses the entire width of the road and has priority over the vehicle". The premise for introducing the obligation to use reflective elements after dusk in an undeveloped area into legal system was a relatively large number of road accidents involving unprotected road users, especially pedestrians. Therefore, it remained to analyze the possibility of avoiding this type of accidents involving pedestrians with and without luminous elements in real conditions.

2. THE INFLUENCE OF LIGHTING PARAMETERS OF THE OBJECT AND BACKGROUND ON THE VISIBILITY RANGE. A SIMPLIFIED PEDESTRIAN NOTICE MODEL IN NIGHT CONDITIONS

The driver's perception of objects along a certain road section is closely related to the change in visibility. The consequence of this situation is a change in the level of road safety. The visibility of the objects along the road and the road itself depends on several factors. The most important of them are undoubtedly the level of road illumination, the contrast of objects and background, the degree of background and object luminance, as well as the adaptation of the driving sight and the angular size of objects, that is the observation distance (Żagan, Mazur, 1997; *Wypadki drogowe…*, 2006; Wolska, 1999).

Figure 1 shows the dependence of the background luminance on the object threshold contrast – the greater the background luminance, the greater the threshold contrast of the obstacle (Unarski, Zębala, 2006).

When analyzing the scope of perceiving obstacles in unfavorable lighting conditions, e.g. at night or after dusk, the following vision states should be indicated as (Żagan, 2014):

- negative contrast that occurs when the background luminance value exceeds the obstruction luminance value;
- positive contrast that occurs when the luminance values are inverse.

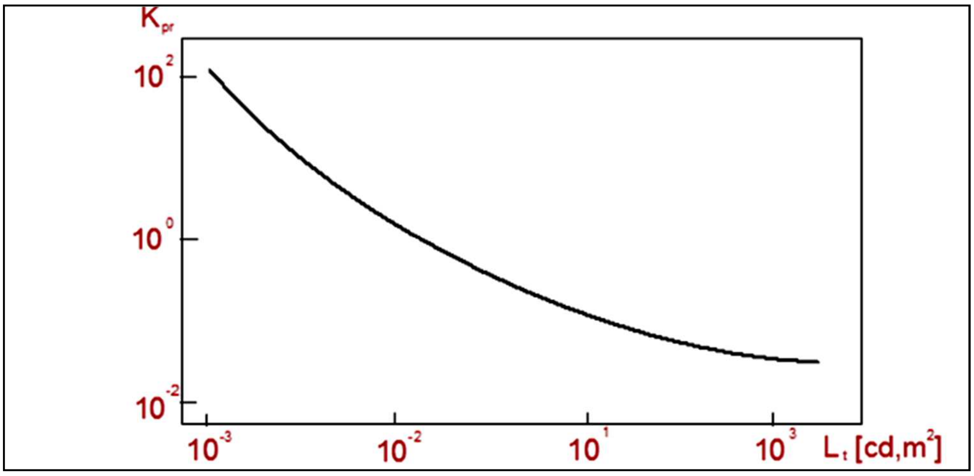

Fig. 1. The dependence of the background luminance on the threshold contrast of the obstacle

The observations of the conducted research on the scope of the possibility of noticing a pedestrian (dressed in uniform color clothes) in the area of the dipped beam of a vehicle without additional light elements (Reza, Wójcicki, 1994) indicate that the pedestrian's lower limbs will be noticed first, and then the torso. This order of noticing an obstacle is dictated by the direction in which the beam of the dipped beam lights is formed. In order to improve the safety of an unprotected road user outside built-up areas, on July 26, 2014, the legislator decided to introduce an obligation to use reflective elements by all pedestrians as road users.

The issue of accidents involving unprotected road users, and pedestrians in particular, is one of the most difficult legal problems that is the subject of struggle by both, procedural bodies and experts. As part of their duties, they perform, inter alia, reconstruction of road accidents in order to determine the range of pedestrian visibility. This reconstruction is the basis for inferring the causes of road accidents and for establishing the perpetrator of the event (*Wypadki drogowe…*, 2006; Prochowski, Unarski, Wach, Wicher, 2008; *Zbiór referatów…*, 2006). It should be noted that each traffic incident is characterized by individual features, therefore, an individual approach is also used to consider them. There are no patterns that could be used in a template manner for every traffic incident involving (not only) a pedestrian in night conditions.

The literature on the subject (*Wypadki drogowe…*, 2006) provides a basic mathematical scheme of noticing a pedestrian illuminated with dipped beam, depending in the properties and parameters of a given vehicle, however, it is not applicable during various road, weather and environmental conditions.

On the basis of the discussed model, it is generally assumed that a pedestrian located in the area of the beam light illuminating him at a minimum height of 25 to 30 cm from the road level, with simultaneous correct observation by the driver of the changing traffic and road conditions, will theoretically be noticed from a distance which results from dependence:

$$L = L_0(H - h)/h$$

where: L_0 – range of the distribution of the dipped beam on the road surface,
H – distance from the axis of the headlamps to the road surface,
h – pedestrian lighting height (30 cm from the road Surface) so that he is noticed by the driver.

The algebraically determined distance on the basis of a mathematical model is only a theoretical value, because when determining the actual distance of perceiving the object, it is advisable to take into account the possible change in both, the range of visibility related to weather conditions, and natural lighting. The dipped beam is designed to illuminate the road ahead of the vehicle. However, due to the formulation of the beam of the dipped beam headlamps as scattered light, the rays of which are also reflected from road infrastructure elements at different angles, the range of visibility of a pedestrian at night with reflective elements should be examined in relation to a specific vehicle, as well as there should be examined the difference in the perception distance of a pedestrian equipped with luminance elements of different colors and the obtained results should be considered in terms of the possibility of avoiding a road accident by stopping the vehicle in front of a pedestrian.

3. PURPOSE AND SCOPE OF THE RESEARCH

The experiment was aimed at testing (checking) the range of visibility of a pedestrian equipped with reflective elements of different colors in natural conditions of night time using dipped headlights.

The tests were conducted under the following conditions:

- lighting: night time, hours from 11:30 pm to 00:45 am,
- road measurements section: straight, 365 m,
- road type: two-way, with a single lane (no road signs),
- area: outside built-up areas,
- type of surface: asphalt,
- weather conditions: moderate wind, partly cloudy without precipitation,
- direction of research (observation): north-eastern,
- air transparency – normal.

The following aids were used to conduct the research:

- Audi A4 B8 passenger car, year of production: 2009, dipped and high beam headlamp – combines, halogen H1 bulbs,
- respondents: 32 people aged 20–22,
- distance meter: measuring wheel “Nikel System M100”,
- reflective band – yellow,
- reflective band – orange.

During the experiment, the scope of the visibility of a pedestrian by the respondents with the dipped headlights was examined. The experiment was divided into two trials: in the first – the pedestrian was equipped with a yellow self-tightening prismatic band placed on the forearm, and in the second – an orange prismatic band. The distance between the vehicle and the pedestrian at the start of the maneuver was approx. 500 m, which was the basis for calculating the difference in the distance between the range of visibility of a pedestrian with, and without the reflective element.

4. RESULTS AND ANALYSIS OF THE CONDUCTED RESEARCH

The graphical summary of the results of the experiment is shown in Fig. 2, while Fig. 3 shows the extreme results of perceiving a pedestrian equipped, first with a yellow and then an orange reflective band placed on the forearm. The results in terms of the avoidance of a road accident are presented in Table 1.

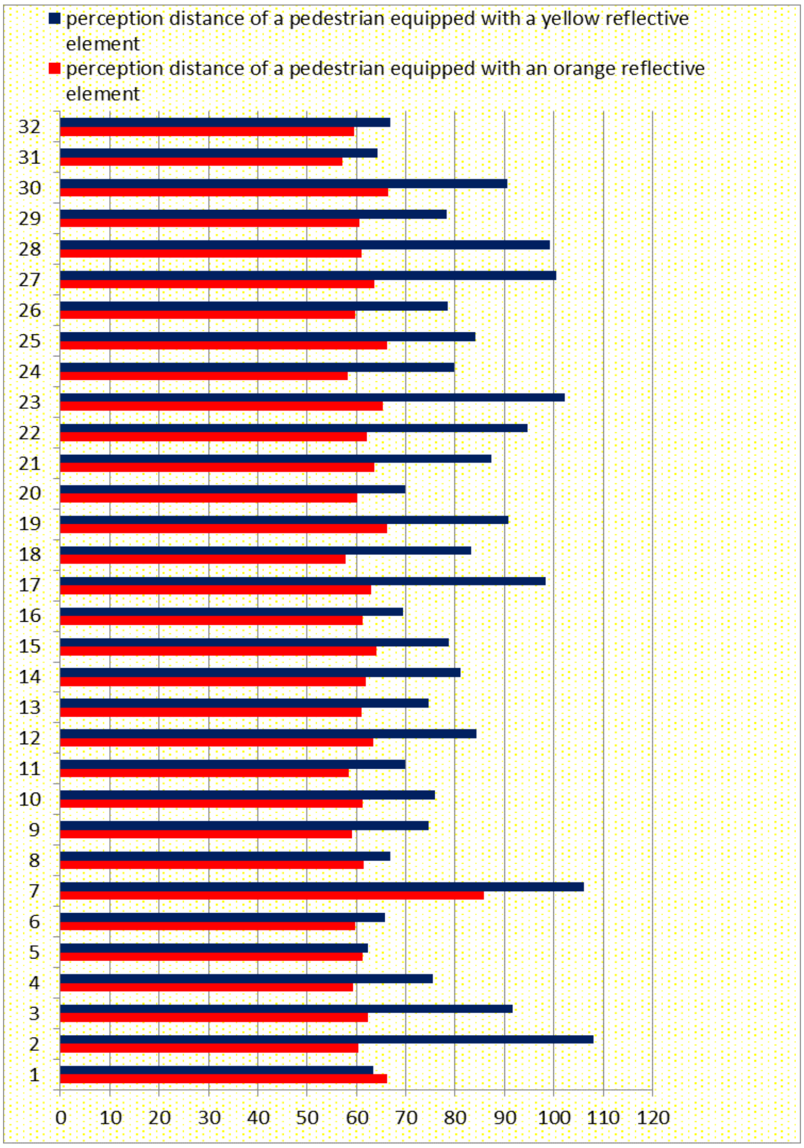

Fig. 2. The results of the distance of perceiving a pedestrian within the dipped beam (vertical axis – subjects, horizontal axis – distance in meters), blue – equipped with yellow reflective element, red – equipped with an orange reflective element

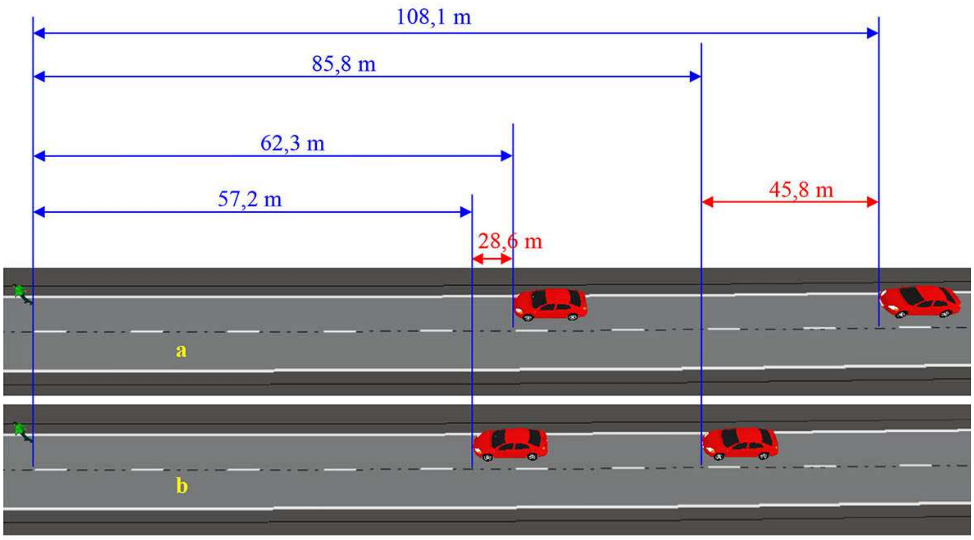

Fig. 3. Graphical representation of the spread of the results of the research on the distance from being perceived by the respondents of a pedestrian equipped with a yellow reflective element (a) and equipped with an orange reflective element

The conducted analysis shows that the color of the reflective element is of key importance in terms of the possibility of seeing a pedestrian. Research, using the same vehicle and the participation of the same people, showed that pedestrians equipped with a yellow reflective element would have an approximate 72 percent chance of avoiding a road incident, while the same pedestrians would have a chance of avoiding a traffic incident with an orange reflective element, as indicated by calculations, would drop down to 3.1 percent. Figure 4 shows the results of the driver's ability to avoid a road incident depending on the color of the reflective element used by a pedestrian.

In order to verify the significance of the statistical substance, the obtained test results (Tab. 1) were analyzed (Table 2, 3, 4) allowing the assessment of both, the reliability of the obtained results, and the correctness of the inference based on them. For this purpose, appropriate statistical tools were used (Prochowski, Unarski, Wach, Wicher, 2008; *Zbiór referatów*…, 2006), which, depending on the type of obtained results, were based on the tests adopted and valued in the statistics.

The statistically significant results of the research indicate the existence of differences between the normal distribution and the distribution of the variable, and the sizes used in the research were distributions consistent with the normal distribution. For this reason, appropriate parametric tests were prepared during further analysis.

The r/Pearson correlation analysis was performer in order to investigate the relationship between the measurements. Statistically significant results indicate the presence of such relationships.

Table 1. The range of visibility in the dipped beam headlamps of a person equipped with a yellow and orange reflective band and the possibility of avoiding a traffic incident by stopping the vehicle in front of a pedestrian depending on the color of the reflective element

No.	The scope of the person's visibility based on the experiment with a yellow reflective detail [m] *	The scope of the person's visibility based on the experiment with an orange reflective detail [m] **	The possibility of avoiding an accident by stopping the vehicle in front of a pedestrian (YES / NO) for dry asphalt	
			yellow reflective band	orange reflective band
1	63,4	66,3	NO	NO
2	108,1	60,4	YES	NO
3	91,6	62,3	YES	NO
4	75,5	59,4	YES	NO
5	62,3	61,2	NO	NO
6	65,7	59,8	NO	NO
7	106,2	85,8	YES	YES
8	66,9	61,4	NO	NO
9	74,7	59,1	YES	NO
10	76	61,3	YES	NO
11	69,8	58,5	NO	NO
12	84,3	63,3	YES	NO
13	74,6	61,1	YES	NO
14	81	62,0	YES	NO
15	78,8	64,1	YES	NO
16	69,4	61,2	NO	NO
17	98,4	63,0	YES	NO
18	83,2	57,8	YES	NO
19	90,7	66,3	YES	NO
20	69,9	60,2	NO	NO
21	87,3	63,7	YES	NO
22	94,6	62,2	YES	NO
23	102,3	65,4	YES	NO
24	79,7	58,3	YES	NO
25	84,2	66,1	YES	NO
26	78,6	59,7	YES	NO
27	100,4	63,7	YES	NO
28	99,2	61,0	YES	NO
29	78,3	60,7	YES	NO
30	90,5	66,5	YES	NO
31	64,2	57,2	NO	NO
32	66,8	59,6	NO	NO

In order to check the compliance of the distribution of measurements in relation to the normal distribution, it was decided to perform the analysis using Shapiro-Wilk tests, verifying the hypothesis of such compliance.

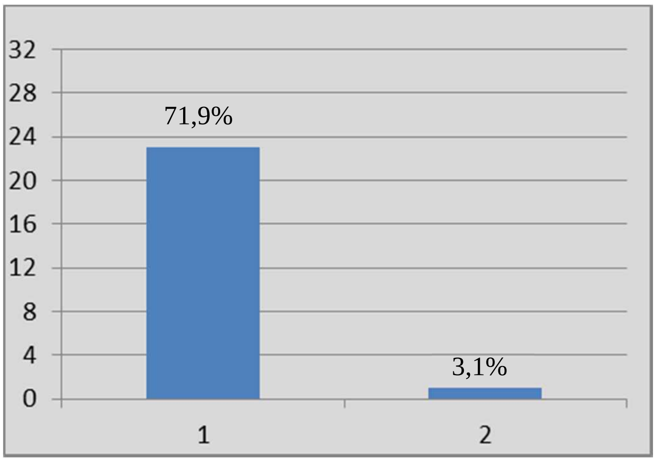

Fig. 4. Percentage and numerical ability of the driver to avoid a traffic incident depending on the color of the reflective element used by the pedestrian (1 – yellow reflective element, 2 – orange reflective element)

Table 2. The results of normality analysis with the Shapiro-Wilk test (Shapiro, Wilk, 1965)

	Shapiro-Wilk		
	Statistics	df	p
Visibility range of a person based on an experiment with a yellow reflective element	0,95	32	0,166
Visibility range of a person based on an experiment with an orange reflective element	0,66	32	<0,001

Table 3. The r/Rearson correlation analysis results

		with a yellow reflective element	with an orange reflective element
	with a yellow reflective element	1	0,48**
	with an orange reflective element		1

p < 0,05*; p < 0,01**

Table 4. Descriptive statistics for measurements

	Average	Standard deviation
Visibility range of a person based on an experiment with a yellow reflective element	81,77	13,29
Visibility range of a person based on an experiment with an orange reflective element	62,46	4,98

The strength of the correlation is measured segmentally: 0-0.1 is absent, 0.1-0.3 weak, 0.3-0.5 moderate, 0.5-0.7 strong, 0.7-0.9 very strong, 0.9-1 almost full. The analysis showed the existence of statistically significant correlation between the assessment of the visibility of a pedestrian (based on an experiment) with a reflective element and the assessment of the visibility of a pedestrian not equipped with such an element. In order to examine statistically significant differences, an analysis was made using the t-Student test (Zieliński, 1972) on dependent samples. The analysis of the test results proved the occurrences amounting to: $p < 0.001$.

5. THE IMPACT OF LUMINANCE ON THE SAFETY OF ROAD USERS

The majority of road users, especially at night, are not aware of the number of hazards that may appear on the road, including limited visibility for vehicle drivers after dark. Using the dipped beam during this time is not only a 24-hour obligation resulting from the regulations, but also a very helpful principle. During the day, the illuminated vehicle is visible to the pedestrians and other road users, and the driver himself uses natural light while driving, whilst at night the car's headlights are the only source of light.

The conducted analysis of the possibility of avoiding the road incident proved that this distance does not allow the vehicle to be stopped in front of a pedestrian. During the reaction, the driver cannot maneuver to change the vehicle trajectory. Therefore, an essential determinant enabling the avoidance of the tragic consequences of the vehicle--pedestrian "relation" is the appropriate visibility of this unprotected road user.

Undoubtedly, adequate pedestrian visibility is of great importance here. The simulation carried out during the tests showed that a pedestrian with a yellow reflective element was noticed by the driver from a distance of 62.3–108.1 m in front of the vehicle, while the same pedestrian with an orange luminous element was noticed by the driver from a distance of 22.4–33 m. Such a distance (even when assuming the administratively permissible speed), unfortunately, in 97% does not allow the driver to make the right decision resulting in avoiding a road incident. The driver simply has no time to stop his vehicle or avoid the "obstacle" noticed late. The conducted research has shown that the color of the reflective element used by a pedestrian is extremely important in order to spot it and undertake defensive maneuvers to avoid an accident. The pedestrian is noticed too late by the driver.

It should be emphasized that the research indicated in this article is real research, carried out in actual road conditions, in which people participated as actual road traffic participants. The provisions of the Act of June 20, 1997, Road Traffic Law (The Act of June 20, 1997) (in article 11, paragraph 4a, article 12, paragraph 6 and in article 41) require the use of reflective elements, however, they do not specify the type or technical parameters or the manner of wearing these elements. Therefore, unprotected road users often show their own inventions and use any bands attached to clothing, reflective lanyards, road vests, or even a light source from mobile phones or flashlights to improve their visibility. Reflective elements of yellow and orange colors were used in the research, without testing to determine their reflectivity characteristics, because the author's intention was to use items available in commercial reality for research.

It is known that objects that do not emit light by themselves can be seen from different distances under night-time conditions, depending on the contrast between the subject and the background. In order to be able to see any object in difficult lighting conditions, there must be a difference in luminance or color, i.e. contrast. In order to distinguish the object from the background, there must be a difference in their luminance values, otherwise the object cannot be distinguished from the background. As the contrast increases, the viewing conditions improve. For example, reflective lights that do not emit light by themselves, due to their technical properties, can be seen directly in front of the vehicle.

As mentioned, the legislator obliged pedestrians to use the reflective element at night outside the built-up area, but without indicating parameters such as color, size, or location. The conducted research, which concerned the influence of the color of the reflective element on the range of visibility, showed that the color of the used reflective element is an extremely important factor significantly increasing the safety of a pedestrian on the road. Due to the multitude of different types of reflectors, the research work undertaken by the author can be used to assess the usefulness and effectiveness of the reflective elements used, and thus to assess their impact on increasing road safety.

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DOI: 10.7862/rz.2020.hss.41

The text was submitted to the editorial office: November 2020.
The text was accepted for publication: December 2020.