ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) https://doi.org/10.17559/TV-20170320121159
Original scientific paper

Investigation of Traffic Signs Understanding - Eye Tracking Case Study

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Abstract: Traffic signs as part of traffic control plan inform traffic participants about road conditions, dangers, limitations and other information needed for their safety on the road. The meaning of traffic signs is defined by their shape, colour and symbol. The quality of the symbol design, manifested in its simplicity and clarity, can influence the understanding of the traffic signs thus affecting the perception. The aim of the study is to investigate, using eye tracking system, the understanding of warning and mandatory signs based on relevant and measurable eye movements: total visit duration, visit count, average fixation duration and fixation count. It was found that the participants, in order to understand signs, tend to detain longer, more often look back and have more fixations on signs whose meaning is not understood. The results also show that more experienced drivers usually base their understanding on experience thus understanding faster and with less number of fixations as opposed to younger drivers.

Keywords: eye tracking; perception; traffic safety; traffic signs

1 INTRODUCTION

In order to fulfil their functions: to warn, regulate, guide and inform traffic participants, traffic signs should meet certain criteria. One of the most important criteria is visibility, i.e. retro reflection that is particularly manifested in poor visibility conditions. Apart from retro reflection properties, signs should be easily and clearly noticed in complex conditions and should clearly indicate the status of the message (legal, warning or information) and convey the message efficiently without the significant strain on the person's perceptive system. They should also be comprehensible so that drivers can recognize the action (or choice) to be taken [1].

According to [2], the perception of road elements consists of three parts: perceptual processes, termed parsing, and the utilization stage. Perception itself can be 'trained' to a certain extent so more frequently practised processes require less attention thus becoming more or less automated. On the other hand, processes that require higher level of attention are known as controlled [3].

Considering all traffic signs, it can be concluded that the driver's sign perception will greatly depend on the position of sign. If the sign is located in their focus of expansion, drivers will notice it before as opposed to the sign, which is located outside this area [4]. Furthermore, if the design of sign, i.e. its symbol, is too detailed and too complex, drivers will have difficulties in understanding it. That will, to some amount, reflect on driver's appropriate reaction. Generally speaking, it may be concluded that the more information traffic sign includes, the more complexity it imposes to driving operations [5].

Due to the all above mentioned when designing the sign it is important to take into consideration the implementation of a message or pictogram that is already known to the driving population or is already used in another context in order to ensure needed time to perceive and parse a traffic sign [1].

Recent scientific researches have shown that the drivers perceive small number of traffic signs even though their role is quite significant in the area of traffic safety. Johansson and Rumar [6] found that drivers are aware of only 17% of pedestrian crossing signs and 78% of speed limit warning signs, which points to the fact that the sign category greatly influences driver's awareness of traffic signs. This conclusion was also confirmed in [6] where results imply motivational rank order between the signs and driver's behaviour. Namely, the research showed that the 'warning sign' was too ambiguous and did not affect the driver in the sense of decreasing the speed, while the sign 'children on the road' even though it implies a direct warning, loses its importance given the fact that in most cases children are not on the road. On the other hand, the speed limit caused the reaction among drivers because of possible punishment for non-compliance. Several other studies recorded similar results of driver's awareness of traffic signs:

- Johansson and Backlund (1970) [7] - between 25% and 75%
- Milosevic and Gajic (1986) [8] - between 2% and 20%
- Drory and Shinar (1983) [9] - recall levels less than 10% during the day and 16.5% at night.
- Macdonald and Hoffmann (1991) [10] - between 26% and 39% depending on the driver's experience
- Costa and Simone (2014) [11] - 25.06% of signs were looked.

The results of the mentioned studies suggest that the motivation is dominant but not the only factor in the process of the perception of signs. According to [10], physical properties of both the sign and its environment are also found to affect the perception of signs.

The aim of this study is to investigate the understanding of traffic signs and explicit orders in the Republic of Croatia by using eye tracking system. The development of light and non-invasive eye tracking systems has enabled their simpler and broader application in the researching of driver's perception. The research conducted in [12], evaluated the driver's attention of regular road signs in comparison to attention when using a dedicated in-vehicle ITS system. The results showed that in-vehicle signs facilitated an increase in the frequencies of stopping for both younger and older drivers at intersections with relatively short yellow onsets. The authors in [13] by implementing driving simulator analysed drivers' eye movement parameters such as fixation number and duration when they were reading traffic signs with various information quantities in different speeds. Results showed that the fixation distribution has a high correlation with

driving speed and information quantity. In other words, as the amount of information increases or the driving speed increases, the number of fixations increases and their duration too. This results in drivers' less visual cognition to front lane.

From all the above mentioned, it can be seen that recent scientific activity was directed towards the analysis of the influence of traffic signs to driver's behaviour. It can be also seen that symbols used on signs were not researched with the application of eye tracking system. The system can gather precise and objective data in regard to the number and duration of fixations. Accordingly, to the best of our knowledge, this research represents the first study using eye tracking system in terms of understanding traffic signs.

Furthermore, one of the reasons for conducting the research is the initiative to develop new Regulations on Traffic Signs in the Republic of Croatia. The results of the study could help competent authorities in the development of new legislation in terms of understanding in order to detect problematic signs and suggest possible improvements.

2 DATA COLLECTION METHODOLOGY

According to current regulation [14], it is allowed to set up 50 warning signs and 62 mandatory signs in the Republic of Croatia. Since the number of signs is quite big, it cannot be expected from the drivers to remember the meanings of all signs. Thus, the symbols of signs should be indicative, clear and logical. Since the aim of the study is to gain insight into the understanding of traffic signs, the research was conducted in lab conditions in the Department for Traffic Signalization, Faculty of Transport and Traffic Sciences.

2.1 Participants

For the purpose of the study, 43 potential volunteers (23 females and 20 males) were engaged in the research. They fulfilled a survey about sex, age and driving experience. After filling the application, potential volunteers were tested with eye tracking glasses in order to see if they were suitable for the research. Three volunteers failed initial testing due to a problem with the calibration of the eye-tracking glasses. The final sample, therefore, consisted of 40 participants, 20 females and 20 males (M = 36.19, SD =12.86, minimal age 20 years, maximum age 63 years) with an average driving experience of 16.83 years (Tab. 1). Participating volunteers received no compensation for their cooperation in the research and their knowledge of traffic signs was not assessed.

2.2 Analysed Traffic Signs

The participants were tested on warning signs and mandatory signs since they are considered the most important sign categories in traffic safety. Altogether, 50 warning signs and 55 mandatory signs were analysed. Seven mandatory signs were discarded from the research since their meanings were explained with symbols and the text so participants could easily understand their meanings (Fig. 1). All signs that were used in the research are in accordance with the current legislation relating to traffic signs in the Republic of Croatia [14].

Figure 1 Examples of discarded mandatory signs [14]

2.3 Instruments

In order to get accurate and objective data in relation to the number and duration of eye fixations to a single traffic sign, authors used sophisticated eye tracking system Tobii Pro Glasses 2. Glasses are equipped with four cameras, which locate the position of an eye pupil, and HD camera, which records area in front of the participant (Fig. 2).

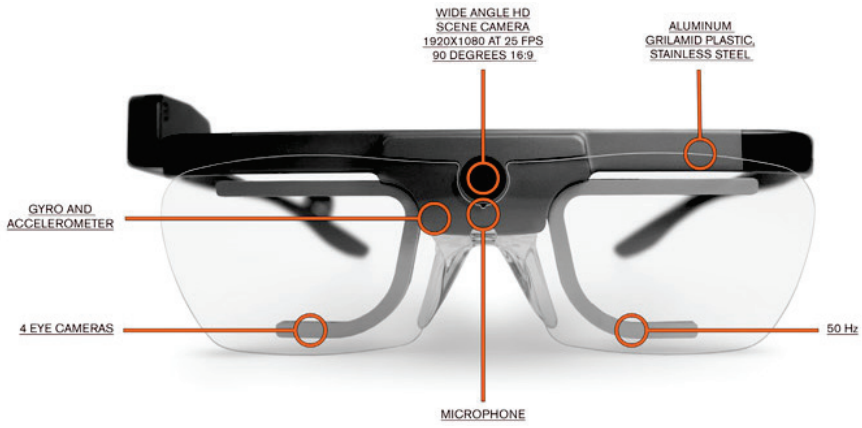

Figure 2 Tobii Pro Glasses 2 [15]

The glasses track the exact fixations of a person in real time, which shows their focus and attention, while simultaneously enabling person to freely move and function as usual [16]. Since the design of glasses is non-invasive and simple, glasses enable normal participant's behaviour thus providing more valid and relevant results.

2.4 Procedure in Conducting the Research

Before the research was conducted, all components of Tobii eye tracking system were assembled according to manufacturer's instructions. Components consist of Tobbiglasses, device for storing video and tablet for controlling the operation of eye tracking system.

Before the research started, calibration of Tobii glasses was done separately for each participant. It was conducted in a way that the participant would put glasses and direct his/her view toward calibration board. After the calibration, its accuracy was checked so that calibration board would move left, right, up, and down and checked whether the participant's view was still on calibration board. The process of calibration is shown in Fig.3.

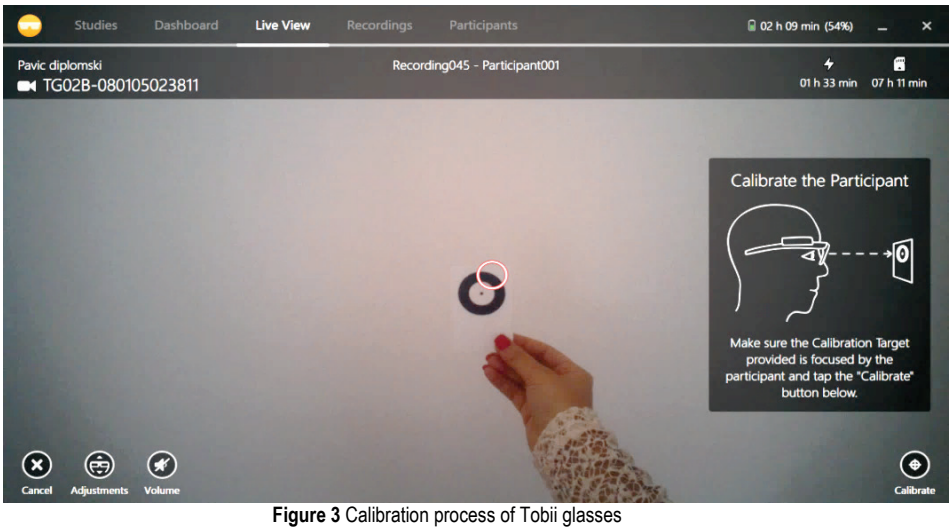

Figure 3 Calibration process of Tobii glasses

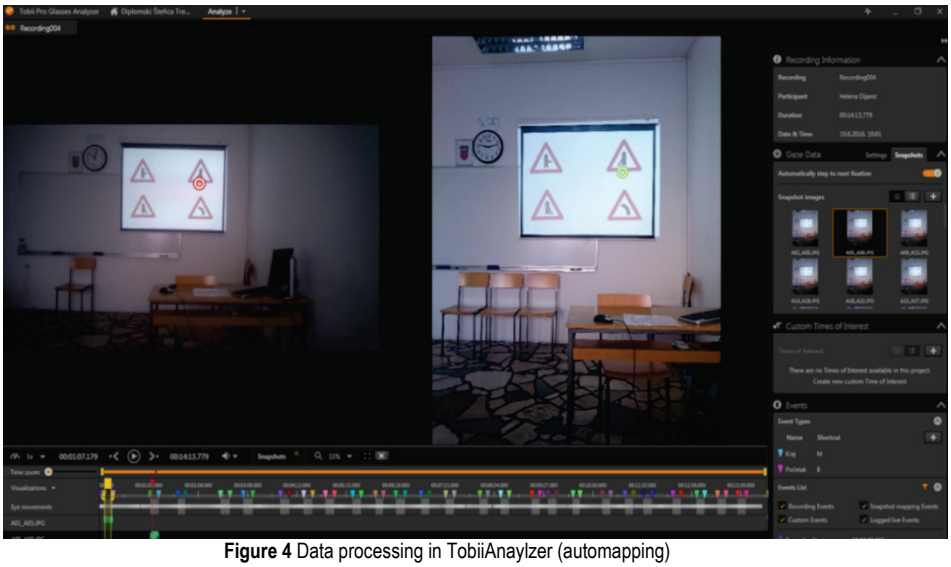

Figure 4 Data processing in TobiiAnaylzer (automapping)

After the calibration, participants were explained the research procedure but not the aim of the research so as not to influence the participants' answers and consequently the results. The procedure was explained in short guidelines in order to ensure quality data. The suggested guidelines were the following:

1. There are four traffic signs on each slide.
2. Observing traffic signs is done by watching signs in all directions.
3. During observation, head should be still and it should not move.
4. Observation of traffic signs is only tracked by eye movements.
5. Participants start observing traffic signs on given cue (GO) and cue (STOP) for stopping the observation – duration of observations is 10 s.
6. After duration of 10 s participant should state the meaning of each traffic sign and should point out whether it is a warning sign or mandatory sign.

After the procedure was explained, the participants were positioned in front of the board on which traffic signs were projected. As explained in guidelines, participants were asked not to move their heads during research but only eyes when observing four traffic signs on each slide. On the cue GO the participant had 10 seconds to observe traffic signs after which the meaning of each sign should be stated. During the explanation of the signs, participant could relax and move head freely after which he had to go back in the position and continue with the observation of next slide.

Table 1 Gathered data

Part.	A – signs which were understood				B – signs the participants did not understand				Sex	Age	Driving exp.
	TVD (s)	VC (num.)	AFD (s)	AFC (num.)	TVD (s)	VC (num.)	AFD (s)	AFC (num.)			
1	2.89	5.98	2.85	106.77	3.16	7.15	3.13	131.80	F	23	5
2	2.30	2.01	2.28	111.17	2.93	6.25	2.89	147.50	F	22	4
3	2.40	2.09	2.39	115.62	3.09	5.33	3.05	155.30	F	25	6
4	1.59	4.17	1.62	79.24	2.05	8.15	2.35	104.46	M	24	6
5	2.10	3.43	2.07	100.82	2.80	9.35	2.78	140.52	M	24	6
6	2.10	3.67	2.17	109.50	3.33	7.89	2.46	131.11	M	26	5
7	2.32	2.00	2.31	105.78	2.56	6.41	2.51	136.14	F	24	4
8	1.76	3.01	1.76	83.85	2.07	8.50	2.05	106.47	F	25	7
9	1.59	3.73	1.56	73.11	2.18	10.20	2.11	111.70	M	23	5
10	2.33	1.93	2.43	110.00	2.64	5.90	2.37	149.90	F	28	6
11	2.10	2.97	2.06	99.02	2.34	7.44	2.26	137.48	F	28	8
12	2.07	2.78	2.04	99.39	3.07	5.67	3.01	157.50	M	28	10
13	2.15	2.86	2.00	100.10	3.10	5.94	2.64	144.58	F	36	17
14	2.22	3.01	1.98	104.59	2.68	5.89	2.97	135.62	M	42	24
15	2.09	2.99	2.22	113.60	3.30	5.73	3.40	140.89	M	53	33
16	2.45	3.52	2.73	110.40	2.98	6.12	3.61	151.36	F	48	29
17	1.96	2.78	2.12	102.30	3.12	5.53	2.89	146.82	M	55	37
18	2.37	3.60	3.10	114.90	3.48	6.11	3.41	144.50	M	60	40
19	2.89	4.20	3.90	118.15	4.68	8.82	4.59	155.63	M	63	44
20	2.11	2.84	2.32	105.62	3.24	5.55	3.37	137.10	F	47	28
21	1.68	2.45	2.29	96.75	2.10	6.24	4.00	109.74	F	57	38
22	2.31	2.99	1.76	82.72	2.76	6.72	4.45	128.94	F	36	16
23	1.88	2.41	2.01	101.55	2.69	6.49	2.64	111.45	F	55	35
24	1.88	2.74	1.99	95.96	2.60	8.24	3.84	118.90	M	48	29
25	1.75	2.74	2.40	98.18	2.69	5.38	2.13	111.22	F	44	20
26	2.80	3.25	3.87	122.44	4.78	8.28	2.07	129.77	M	28	9
27	2.56	3.38	2.95	111.45	4.48	7.23	2.68	140.74	M	22	2
28	1.45	2.77	2.65	104.58	2.88	6.66	2.88	107.52	M	37	18
29	2.03	2.88	1.66	79.79	2.54	5.56	3.58	116.54	F	52	30
30	1.74	2.89	1.85	87.47	3.33	5.98	4.09	108.72	F	42	21
31	2.02	3.04	2.29	84.76	2.26	6.79	4.47	118.10	M	37	19
32	1.59	2.78	1.79	82.40	2.44	6.53	4.21	111.24	F	34	15
33	2.88	4.82	2.36	126.75	4.66	8.98	3.15	138.95	M	21	3
34	2.74	4.83	3.03	115.65	3.89	5.02	3.51	146.60	M	20	1
35	2.66	4.15	3.88	112.21	4.78	5.66	4.48	151.41	M	26	6
36	1.62	2.66	1.84	99.45	2.57	6.12	2.80	110.33	F	48	29
37	1.83	2.51	1.64	85.51	2.49	6.23	3.48	106.25	M	31	13
38	2.85	5.34	3.67	118.65	4.65	6.41	4.57	156.55	F	29	7
39	2.52	4.32	3.79	112.36	4.89	6.55	4.51	163.56	F	25	5
40	1.68	2.67	1.72	82.35	2.33	6.08	4.14	122.12	M	51	33
Av.	**2.16**	**3.23**	**2.38**	**101.62**	**3.12**	**6.73**	**3.24**	**131.88**		**36.19**	**16.83**

2.5 Collected Data Analysis

Software Tobii Anaylzer was used for detailed analysis. Data processing was done by uploading the video for each slide (four signs) and the picture from the same slide. The participants' views from video to picture were located (Fig. 4) via 'auto mapping'. As shown on Fig. 5, the area of interest (AOI) was defined in the uploaded picture.

Figure 5 Ares of interest

According to [17] there are number of countable entities such as saccades, blinks, fixations, smooth pursuits etc. For the purpose of this research data, reflecting total visit duration, visit count, average fixation duration and fixation count for every area of interest and every participant was gathered. Areas of interest (AOI) are regions in the stimulus that the researcher is interested in gathering data about and with that presents a tool for further analysis of eye movement data [17].

3 RESULTS AND DISCUSSION

Gathered data are connected to total visit duration (TVD), visit count (VC), average fixation duration (AFD), and fixation count (AFC) for each sign. The results are shown in Tab. 2. The part of the table marked with letter 'A' shows average values for traffic signs which were understood by the participants, i.e. they knew their meanings. The part of the table marked with letter 'B' represents average values for signs the participants did not understand.

From the results in Tab. 1 it can be concluded that the drivers had shorter TVD when they knew the meaning of the signs as opposed to those they did not understand. Average total visit duration of all participants who understood the meaning was 2.16 and among drivers who did not understand the meaning was 3.12 seconds, which is the difference of 44.44%. Apart from the noticed

difference, considerable difference in visit count for each area of interest was noted. Average VC of all participants for traffic signs whose meaning was understood was 3.23, while average VC for signs that were not understood was 6.73, which is the difference of 108.35%. As visit count represents the number of views in AOI it can be concluded that the participants have re-viewed more of the signs they did not understand in order to get closer look at the symbols thus trying to understand their meanings.

The average duration of fixations of the participants for the signs that were not understood was 2.38 seconds, while for the signs they understood 3.24 seconds, which is the average difference of 36.13%. In addition, the difference between average fixations counts of signs that were understood compared to those that were not understood is 29.77%. It may be concluded that the participants actively scanned the signs they did not understand and spent 36% time more by focusing on them in order to understand their meanings.

After T-test was conducted for every measured entity, it was confirmed that there was statistically significant difference between the results that participants showed for signs they understand compared to those they did not understand.

The results also show the difference in values among older participants compared to younger ones with shorter driving experience. From the stated reason, participants were divided in two categories: participant with driving experience of less than 10 years and participants with driving experience of more than 10 years. Accordingly, values of each measurable entity were analysed separately for A and B group of signs. As shown in Tab. 3, after T-test was conducted it was confirmed that there was statistically significant difference between drivers with driving experience less than 10 years compared to drivers with driving experience longer than 10 years for each measurable entity separately for A and B group.

Table 3 Results of T-test

		TVD		VC		AFD		AFC	
		< 10years driving exp.	> 10 years driving exp.	< 10 years driving exp.	> 10 years driving exp.	< 10 years driving exp.	> 10years driving exp.	< 10 years driving exp.	> 10 years driving exp.
A	Mean	2.36	1.98	3.61	2.91	2.61	2.19	106.35	97.75
	Variance	0.178	0.111	1.409	0.163	0.588	0.281	210.154	132.048
	Observations	18	22	18	22	18	22	18	22
	$P(T \leq t)$ two-tail	0.0036		0.0132		0.0048		0.0428	
B	Mean	3.40	2.87	7.26	6.29	2.94	3.48	137.77	126.38
	Variance	1.106	0.300	2.111	0.694	0.693	0.468	280.255	314.699
	Observations	18	22	18	22	18	22	18	22
	$P(T \leq t)$ two-tail	0.0489		0.0011		0.0297		0.0451	

It can be concluded from Tab. 3 that the average values of all measurable entities were less among drivers of older age and longer driving experience. Generally, drivers' age and their driving experience have a significant negative impact on the sign perception and experienced drivers, while driving, rely more on experience and instinct perceiving fewer elements from the environment [10, 18]. The results of the study also show that more experienced drivers rely on experience, which is the reason why they understood the signs faster, and with less eye fixations. When compared to younger drivers, they even had shorter fixations on signs they did not understand which can be explained by the confidence gained during driving experience. Namely, due to their confidence, experienced drivers stopped looking and inspecting sings faster than younger drivers do even though they did not understand them. On the other hand, younger drivers, due to their personal insecurity, would detain longer on traffic signs trying to inspect the signs in details and understand their meanings.

Furthermore, if more than 10 of participants did not understand the meaning of a certain sign, that sign was marked as problematic in terms of understanding. Altogether, there were 25 signs marked like that. Signs that have shown to be problematic were those that: indicate approaching the crossing over the railway without barriers or semi-barriers (a) indicate approaching the crossing over the railway with barriers or semi-barriers (b), indicate the place where the road crosses the railway without barriers or semi-barriers with two or more tracks (c). Even though the participants understood that those signs represent the warnings for level crossing countdown markers, they did not know what type of crossing it was (Fig. 6).

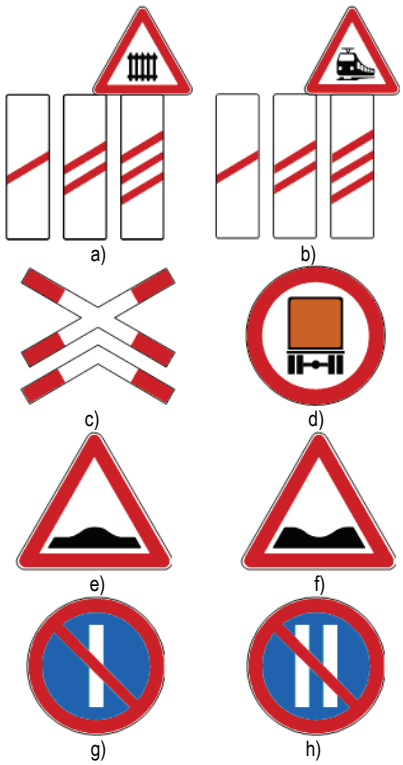

Figure 6 Examples of problematic signs in terms of understanding [14]

Apart from the mentioned, the problematic signs in terms of understanding were: prohibitory traffic signs for vehicles carrying hazardous substances (d), signs indicating the vicinity of the road hump (e) or road depression (f), even (g) / odd (h) dates parking signs (Fig. 6).

Possible reason for the problems in understanding could be that drivers have rarely or in some cases never (g, h) come across those signs. According to data from Hrvatskeceste Ltd. there are 149,435 traffic signs on Croatian roads of which 2.3 % are signs that in this study were detected as problematic which surely influences their understanding.

The other reason is the design of signs, which confirms the fact that participants did not report the problem or not understanding of non-frequent signs on the roads of the Republic of Croatia (range between 0.002% and 0.07%).

4 CONCLUSION

The aim of this research was to evaluate and investigate to which extent drivers understand warning signs and mandatory signs according to relevant and measurable eye movements: total visit duration, visit count, average fixation duration and fixation count.

The main research findings show that there is a statistically significant difference for every measured entity between the results participants had for signs they understood and those whose meanings they did not understand. The results show that all four measured entities are higher for signs that were not understood. In other words, participants would stop for a longer period at the signs they did not understand, they had more fixations and after looking away, they would look again in order to understand them.

Furthermore, statistically significant difference was noted between participants with driving experience less than 10 years and those with driving experience longer than 10 years.

The results suggest that the experienced drivers base the understanding of traffic signs on their experience thus understanding the signs faster and with less number of fixations. They had less fixations and shorter duration to the signs they did not understand when compared to younger drivers. This could be explained with the self-confidence gained during driving experience. Due to their experience more experienced drivers would stop looking and studying the signs much faster as compared to younger drivers even though they did not understand them. The results are in accordance with the previous studies [18, 10] stating that the drivers' age and their driving experience have a significant negative impact on the sign perception and that experienced driver's rely more on experience and instinct perceiving fewer elements from the environment.

On the other hand, younger drivers, due to their insecurity, tend to detain longer on traffic signs in order to study the sign in details and understand its meaning.

Furthermore, the study noted 25 problematic signs in terms of understanding. The reason for misunderstanding could be that drivers have rarely or in some cases never (g, h - Fig. 6)) come across that sign which is the reason they often forget their meaning. The other reason is connected to the design of the symbol.

Possible solutions for lack of clarity of certain symbols can be seen in redesigning it in accordance to ergonomic principles or by giving extra explanations of the signs on additional boards.

The resulting findings primarily extend the existing knowledge about the understanding and the perception of traffic sings, which are of vital importance for all participants in terms of traffic safety. Furthermore, the results can directly help the competent authorities in drafting new legal regulations both in Croatia and in other countries.

The main limitation of this study is relatively small sample with limited diversity in the age and driving experience and driving culture. In addition, the study was based on the signs in Croatia and before reaching reliable conclusions and their implementations in a wider context of traffic safety further researches should include signs from other European and world countries. The aim of authors' future research will be expanding the study to other countries and including participants from different backgrounds in order to increase the standardisation of traffic signs throughout the whole Europe.

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