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Drivers' experiences of presence sensitive roadway lighting match experiences of traditional road lighting – a case study in Finland

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Drivers' experiences of presence sensitive roadway lighting match experiences of traditional road lighting – a case study in Finland

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Abstract. This research aimed to test and study presence sensitive roadway lighting in a housing area in Finland, and to evaluate drivers' experiences and attitudes of it. The lighting adapted both to motor vehicles using the road and to the measured traffic density along it. The case study was conducted on a collector road in Salo, a town in southern Finland. New, controllable LED lighting with PIR (passive infrared) presence sensors was built along the road, and test scenarios were designed, programmed, and tested. Drivers' experiences and attitudes of the lighting were collected in a three-phase evaluation with questionnaires from the community of about 1000 households using the road as part of their daily mobility. The results indicate that as an experience, presence sensitive lighting in a road environment was at least as positive as traditional, uncontrolled lighting. The experiences of presence sensitive lighting did not differ from the experiences of uncontrolled lighting regarding pleasantness, uniformity, glare, and road visibility. Most of the drivers (86 %) did not notice any dynamic change in lighting. When informed about the tested lighting strategies, most of the participants (72 %) would prefer either one of the intelligent lighting modes to be the permanent lighting solution. The results encourage the use of intelligent lighting in striving towards more sustainable lighting solutions while maintaining user comfort and safety.

1. Introduction

There is a growing need to reduce energy consumption of road lighting while maintaining user comfort and safety. Applications of adaptive and intelligent lighting technologies offer solutions for this demand. The concept of adaptive lighting refers to an intelligent lighting system, which is equipped with sensors and actuators that allow the system to dynamically adapt to the current conditions or to the needs of individual users [1]. Adaptation in lighting systems can be achieved through sensor networks that gather information from the environment, such as the flow of traffic, and feed it to a closed-loop adaptive system. Through adaptive behaviour, the system can offer energy savings and cost efficiency. [2,3] One example of adaptive systems is *presence sensitive roadway lighting*, i.e. lighting that is programmed to adapt to the presence of vehicles or people. The energy saving potential has been demonstrated both in simulations and in real world case studies [4,5,6]. When designed wisely, adaptive lighting can offer, besides energy savings, added experiential value for illuminated environments [7].

There is still a lack of real-world research scrutinizing the experiences of drivers in adaptive and intelligent roadway lighting situations which hinders the introduction of applications by cities and municipalities. A study from 2011 by Atıcı et al. [8] focused on a pedestrian setting, noting that “other forms of mobility cases, such as cyclist and vehicular, should also be analyzed.” Recent research from Finland concerning dimmed road lighting in an urban road suggests that it is feasible to reduce ”road lighting intensity when car headlights are available” from the drivers’ point of view [9]. To address this gap in knowledge, our research designed and studied presence sensitive roadway lighting in a housing area. The lighting that was tested in our study adapted both to motor vehicles using the road and to the measured traffic density along it, enabling us to evaluate drivers’ experiences and attitudes concerning it. A traditional lighting scenario was also implemented, as we wanted to compare the experiences of traditional and presence-sensitive lighting. Our research questions were the following: How do drivers’ experiences of presence sensitive roadway lighting compare to experiences of uncontrolled, traditional lighting? What are the experiences, opinions, and attitudes of informed participants regarding a real-world implementation of two differing intelligently controlled lighting scenarios: presence sensitive lighting, and presence sensitive lighting based on the measurement of traffic density? The case study was conducted along a collector road in Salo, a town in southern Finland. The study was part of the Sencity – Intelligent Lighting as a Service Platform for Innovative Cities project [10].

2. Methods and materials

2.1. Research setting and participation process

Our case study consisted of a real-world test of presence sensitive roadway lighting, which adapts both to motor vehicles and to the measured traffic density along a collector road. A new, controllable LED lighting with PIR (passive infrared) presence sensors was built along the road, 41 light poles altogether, and test scenarios were designed, programmed, and tested. The luminaire type was Easy LED PRO Flow S 30-850 UP-R 740, with luminaire wattage of 76.0 W, lumen output of 8470 lm, and correlated colour temperature of 4000 K. The mounting height was 10 meters. The manufacturer of the presence sensor and intelligent lighting control system was Lumine. Users’ experiences of the lighting were collected with questionnaires from the surrounding community of about 1000 households that use the road for daily mobility, and from other interested inhabitants of the city. The roadway was used only by cars; the light traffic route for pedestrians and cyclists was located separately in a surrounding forested area.

The study consisted of three scenarios, which tested three different lighting control methods (Figure 1). *The first scenario (‘Traditional’ lighting control method)* ran from 23 Jan – 5 Feb 2017. In this phase, the new lighting was controlled in a basic manner (daylight level based control): during the bright period of the day, the lights were turned off, and during the dark period, they were on at a 100 % control level. The sensor detected the threshold lux level and turned the lights on and off automatically. During *the second scenario (‘Presence sensitive’ lighting control method*; 6 Feb – 26 Feb 2017), a presence-based dynamic control was added to the previous basic daylight level based control. In this phase, the lighting was controlled dynamically so that it was always brightened around a moving car to the maximum control level of 100 %, and in those parts of the road where there was no traffic, it was dimmed down to a 20 % control level. The dimming and brightening were done softly using a 3 second ramp up and down. The bright area around a detected vehicle consisted of five streetlights: the one which detected the car with a passive infra-red (PIR) sensor as well as two forward and two backward lights. In *the third scenario (‘Presence and traffic density sensitive’ lighting control method;* from 6 March 2017 onward, questionnaire deployed 19 Jun – 2 July 2017), a third control method was introduced to complement the two former ones. The introduced method was based on the measurement of traffic density: the lower control level of lighting adapted to the amount of traffic detected along the route. When traffic was dense, for example during the commute-heavy periods in the morning and in the evening, the control level of the lighting was dropped to 70 % on those parts of the road where no traffic was detected. During times of moderate traffic, the level was 40 %, and with the lowest traffic density during the night, the level was dropped to 20 %. The times of sunset and sunrise in Salo varied along the test period being on 23 Jan 16:16 and 09:03; on 6 Feb 16:53 and 08:30; on 6 March 18:07 and 07:11; and on 19 Jun 22:59 and 03:58, respectively.

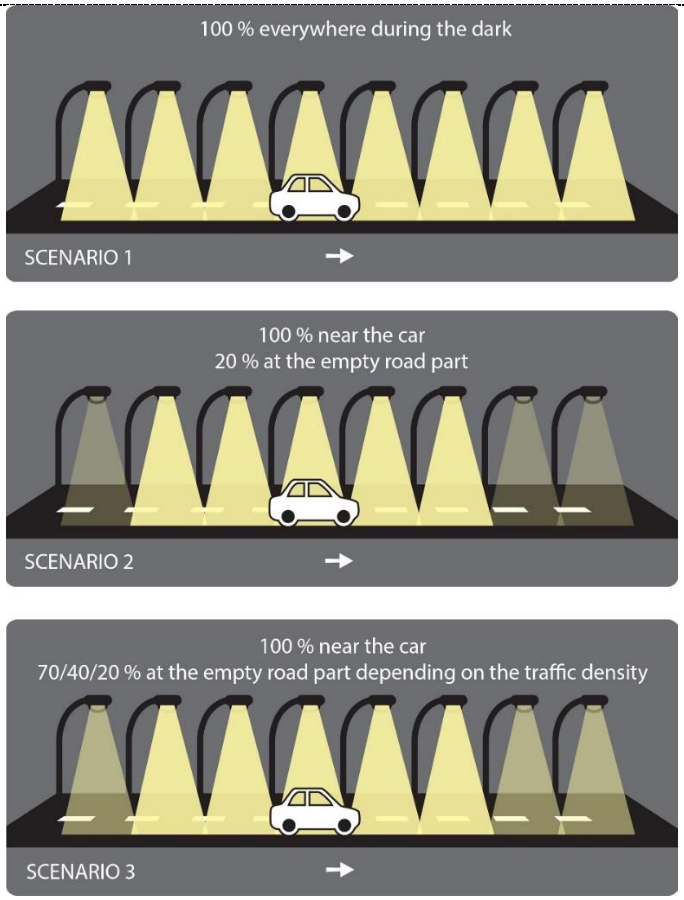

Figure 1. The lighting control principles of the scenarios. Scenario 1: Daylight level based control, Scenario 2: Presence sensitive lighting control, Scenario 3: Presence and traffic density based lighting control.

To study road users' experiences of the test site, questionnaires were deployed. During the first scenario, questionnaires were sent to all inhabitants of the area. While testing for the second scenario, the questionnaire was only sent to those who had explicitly agreed to participate again in the first questionnaire, but the questionnaire was also advertised in local media; this process was repeated for the third questionnaire. In the first and second phase of the testing period, the questionnaires used were almost identical. Prior to answering the questionnaire, participants were asked to drive along the road with the test lighting during the dark period of the day. Since there was no sidewalk or cycle lane on the side of the collector road, feedback from walkers and cyclists could not be obtained. Table 1 contains the number of participants answering to the questionnaires and some demographic data.

Table 1. Information about participants answering the first questionnaire (Q1), the second questionnaire (Q2), both the first and second questionnaire (Q1&Q2) and the third questionnaire (Q3).

	participants	female	male	age under 20-59	age 60+	not local
Q1	124	54	71	97	28	1
Q2	100	41	59	82	18	1
Q1&2	94	39	55	76	18	0
Q3	52	17	35	41	11	1

To gain background information regarding our participants, we asked about their usage of the road and its prevailing conditions during the time when they evaluated the lighting. Other questions concerned their overall impressions of the lighting; the experienced color of the lighting; their experiences regarding the amount of lighting on the road surface and on the surrounding environment; the experienced evenness (uniformity) of lighting; and experiences of glare. The participants were also queried on road visibility – how well they could see the road in front of them and other people moving on it or in the surrounding environment. Participants were also allowed to freely give personal feedback about the lighting. Moreover, participants were asked whether they had noticed any changes in the lighting during different times of the day or during their test drive. Those who answered to the second questionnaire were queried on whether they had noticed any change in the lighting after the first questionnaire. Most of the questions were formulated as scales with ratings on a scale of 0 to 5, with an added possibility for open-ended qualitative commentary.

Table 2. Results about the energy consumption simulation based on PIR sensor data of the date 8.2.2017.

The energy consumption at the test collector road		
SCENARIO 1	**SCENARIO 2**	**SCENARIO 3**
1.1 kWh / lighting fixture	0.5 kWh / lighting fixture	0.6 kWh / lighting fixture
Energy saving as compared to Scenario 1	**55 %**	**45 %**

For the evaluation of the first two scenarios, the participants did not receive any information about the new lighting other than it was accomplished with LED lights and that the lighting control had been developed during that same winter and spring. This was because the objective was to gain feedback from participant experiences that were as genuine as possible, unaffected by previous knowledge. During the testing of the third scenario, the approach was the opposite. Participants received detailed information of the three different lighting control methods that had been tested in each of the scenarios. We were interested in participants' attitudes towards lighting in general, especially those toward intelligent lighting as well as the three tested control methods. Furthermore, our objective was to gain more reflective viewpoints rather than mere reports of raw experiences. At this stage, the questionnaire did not require participants to visit and observe the lighting on site due to seasonal reasons. The third questionnaire was deployed in the summer, and outdoor lighting everywhere in the country was almost completely turned off at the time because of the long daylit periods during the summer months in northern latitudes. In Salo, outdoor lighting was used only for a couple of hours in the dead of night. Thus, a site visit component at this stage did not make sense.

To disseminate information about the lighting, our team had developed an urban dashboard (The City Monitor) [11] in the form of a website. In the dashboard, scalable charts, dynamic visualizations of the lighting behavior, and verbal descriptions of each lighting control method were presented. The scalable charts illustrated the average lighting and energy consumption levels. Figure 2 illustrates the information provided in the website simulation of the scenario 2. In the evaluation process, the participants could choose to answer questionnaires either in an electronic or printed form. With the third questionnaire, only the electronic one had interactive and dynamic simulations, but the printed one contained the same information in picture and textual mode. The PIR sensor data of a single date (8.2.) was used for simulating lighting behavior with the three different control methods, allowing comparison of the energy consumption [11]. The results of the comparison (presented in table 2) indicate great energy saving potential for both scenarios two and three.

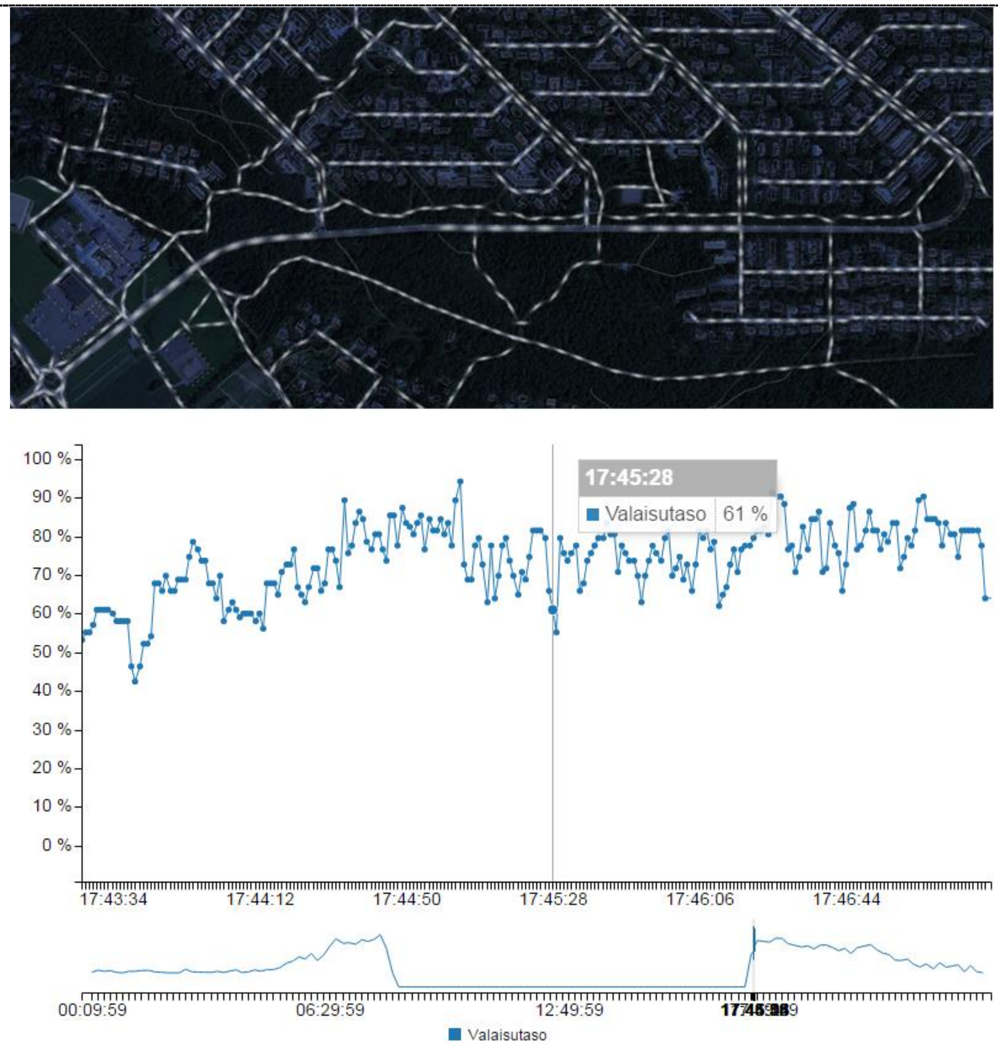

Figure 2. A screenshot of a simulation of scenario 2 as visualized on the dynamic interactive web page.

2.2. *Data analysis methods*

The participant answers to all three questionnaires were organized into Excel sheets and checked for validity. A few participants for the first and second questionnaire were rejected based on information indicating that the participant had not been driving a car or been a passenger in a car along the test road. The answers of all accepted participants were included in the analysis and description of experiences concerning the scenarios 1 and 2, the number of participants being 124 and 100 respectively, but in the statistical comparison of the two scenarios, only those participants were included who had answered both the first and the second questionnaire (n = 94). The answers for the open-ended questions were thematised into important themes and aspects, and explanatory factors for experiences were collected.

The objective was to show that the experience of presence sensitive lighting would be as positive as traditional lighting. A result of having no differences between the experiences of the two scenarios would indicate that. To test whether there were statistically significant differences between the experiences of the scenario 1 and 2, the dependent samples t-test for paired samples was selected as the statistical analysis method. The data included a good sample of 94 road users evaluating both lighting scenarios, the traditional and presence sensor controlled. In the test, the difference scores (D) were used as variables, so for statistical analysis, the difference between the values of each question were calculated for every participant. As this distribution of the differences was fairly symmetrical, testing could be performed as a dependent samples t-test and corresponding 95% confidence interval calculation. If there was no difference between the sample pairs, then the mean of the difference scores would be equal to zero. Therefore, the null hypothesis to be tested was $\mu_D \neq 0$.

3. Results and analysis

3.1. Traditional and Presence-sensitive scenarios

Figure 3 illustrates the results concerning the experiences of all participants evaluating scenarios 1 (traditional lighting, n = 124) and 2 (presence sensitive lighting, n = 100). Generally, the participants gave both lighting scenarios high scores in all the aspects which were queried, and the scores were similar regarding both traditional lighting and presence sensitive lighting. Concerning the general appearance of lighting (0 = very unpleasant, 5 = very pleasant), the mean of the scores was 3.98 with traditional lighting and 3.94 with presence sensitive lighting. When participants were asked whether anything in the lighting disturbed them, 81 % answered "no" with traditional lighting and 82 % with presence-sensitive lighting. While evaluating the uniformity of the lighting on the road (0 = not uniform at all, 5 very uniform) the mean was 3.64 with traditional lighting and 3.70 with presence sensitive lighting. Lighting did not seem to cause much glare while driving, as the mean of the scores (0 = very much, 5 = not at all) was 4.14 with traditional lighting and 4.16 with presence sensitive lighting. Participants were also asked separately how well they were able to see the roadway and others moving on the road and its surroundings (0 = very badly, 5 = very well). Here the mean concerning roadway visibility was 4.16 with traditional lighting and 4.17 with presence sensitive lighting. The visibility of others moving on the road and in the surroundings was experienced as being slightly worse: the mean of the scores was 3.53 with traditional lighting and 3.77 with presence sensitive lighting. This relates also to the evaluation of the amount of light separately on the road and in the surroundings: more participants experienced that there was a sufficient amount of light on the road surface (89 % with traditional lighting, 92 % with presence sensitive lighting) than in the surroundings (74 % with traditional lighting, 79 % with presence sensitive lighting).

The participants were given the possibility to verbally comment on their numerical evaluations, which helped us further understand the experience beyond the scores. Positive feedback was given to both scenarios regarding a sufficient amount of light (*"not too bright", "a sufficient amount of light", "bright"*), the tone of light (*"soft, good tone"*) and the absence of glare. However, some of the same aspects were also criticised in a few comments (*"too weak", "bright LED-lights where lumen values are raised by raising the colour temperature are not sufficient for human eyes"*). Obviously, critical comments were given to the question of whether anything disturbed the participants in the lighting. These negative notions included experiences of glare (several comments), unevenness of lighting, inefficiency of lighting, costs, and the perceived redundancy of lighting. Also, a concern regarding not having enough light by the pedestrian crossings and cross-roads in general was raised.

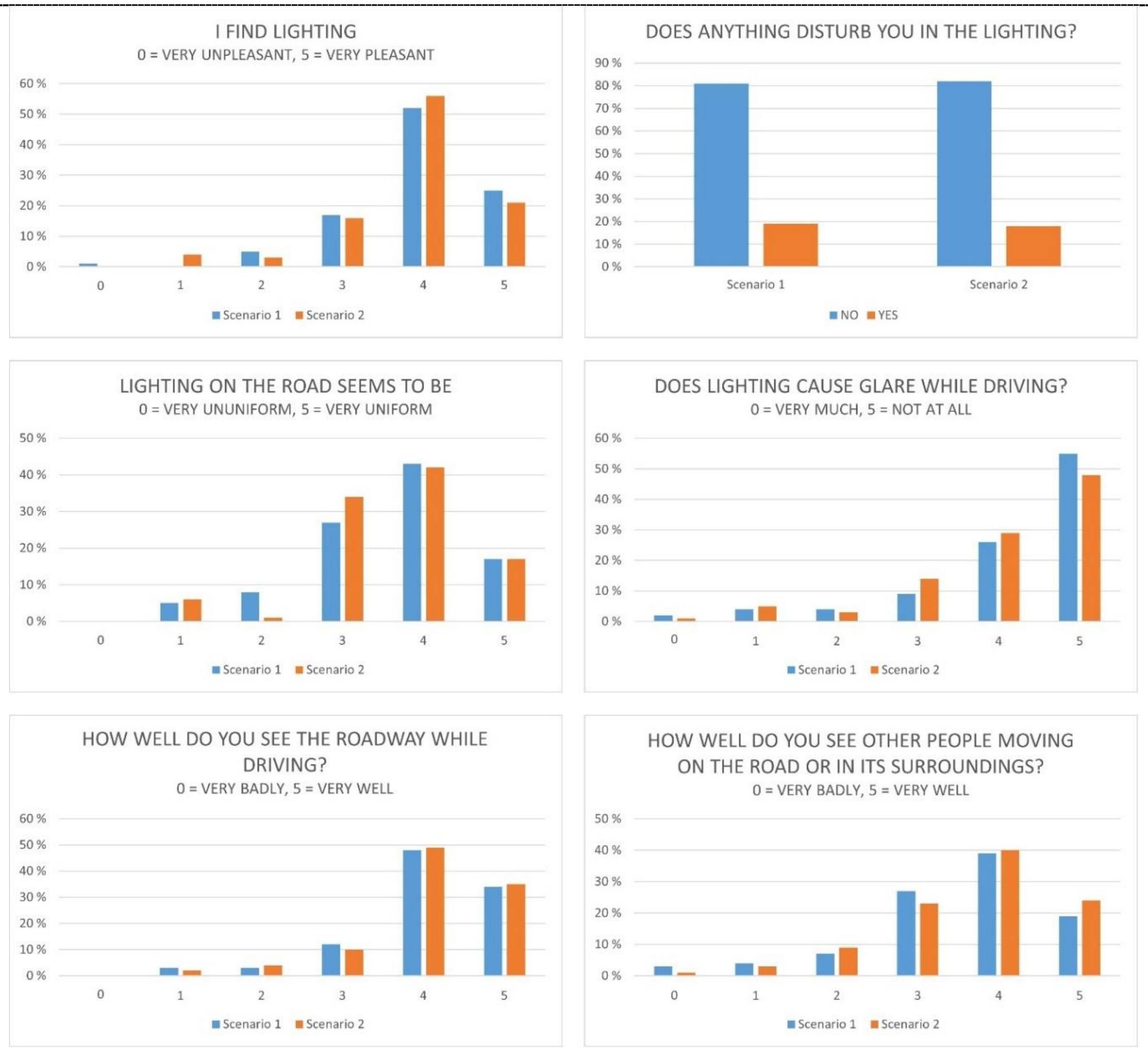

Figure 3. The comparison of participants' scores of Scenario 1 (Traditional lighting) and Scenario 2 (Presence sensitive lighting)

Table 3 presents the statistics from the dependent samples t-tests conducted. For all the questions concerning 1) the appearance of the road lighting in general; 2) the evenness of light distribution on the road surface (uniformity); 3) experiencing glare when driving and; 4) experience of seeing the roadway when driving, the statistical analysis showed no difference between the compared conditions. The p-value in these was between 0.48 – 0.89 indicating that the null hypothesis had to be abandoned and the detected variation between the results is coincidental. The only exception was the question *"When driving, how well do you see the other users of the road and the environment?"* Here the results indicated a slight statistical significance in favor for the presence sensor controlled lighting scenario: $t(94)=-2.296$, $p=0.024$ (dependent samples t-test). Thus, it could be stated that the experiences of presence sensitive road lighting are at least as positive as experiences of traditional lighting, in light of the aforementioned questions.

Respondents to both the first and the second questionnaire were questioned on whether they had noticed any differences in lighting during different times of the day. With the traditional lighting, 97 % had not noticed any differences, and with the presence-sensitive lighting, 93 % had not noticed any differences. There were no differences in the control method during different times of the dark time with the first two scenarios. However, depending on the time of day, the amount of traffic is altered and due to this, also the time when lighting is on at the 100 % control level changes. Additionally, there were two extra questions in the second questionnaire. Firstly, participants were asked whether they had noticed any change in lighting after the first questionnaire. Out of those respondents who had answered also to the first questionnaire, 76 % had not noticed any change. The comments included approximately the same number of remarks about brighter and better lighting as about dimmer lighting; however, most of the evaluations indicating dimmer lighting had added a question mark or also doubted that the reason may have been snow conditions or their own imagination. A couple of participants had noticed that a few broken luminaires had been replaced with new ones, and that lights had been on during a bright day. This was probably due to the testing of the replaced luminaires. Two participants commented about noticing the dynamic dimming and brightening of lighting. One of them had been walking while making the observation. The other commented that the lighting brightens when a car is approaching. Secondly, the participants were asked whether they had noticed any change happening in lighting while they were moving along the test road with a car. 86 % of the respondents answered "no". Of those participants who reported noticing something, only four described noticing dynamic dimming and brightening. The others commented on different types of experiences, for example, they described the lighting to be better, brighter in the dark, having a more pleasant tone, or being dimmer.

Table 3. The results of dependent samples t-tests using difference scores as variables (n=94): mean, standard error, 95 % confidence interval and p-value are presented.

	Mean	SD	95 % CI	p-value
Appearance of the road lighting	0.043	0.775	[-0.116, 0.201]	0.596
Light distribution on the road surface	-0.064	0.878	[-0.244, 0.116]	0.482
Glare when driving	-0.021	1.136	[-0.254, 0.211]	0.856
Visibility of the road when driving	-0.011	0.796	[-0.174, 0.152]	0.897
Visibility of road users and environment when driving	-0.234	0.988	[-0.436, -0.032]	0,024*

3.2. Informed opinions of all scenarios

Here, we report on answers to the open-ended questions of questionnaire 3 that involved all scenarios.

When queried about the participants' opinions regarding *scenario 1* (*"What do you think about this type of a lighting control method where the lighting is kept at the same level?"*), most participants considered this method to be inadequate or not sensible in some way; two participants were of the opinion that it was *"old-fashioned"*, and three thought that it was simply *"bad"*. Most didn't consider this to be a sensible way to light since *"technology enables better control without added costs"*, or they had concerns regarding light pollution or wasteful energy consumption. Curiously, one participant noted that they had thought this was the only possible way, but having perused our questionnaire, the participant concluded that this was *"old-fashioned"*. Thus, it must be taken into consideration that this might be true for some other participants as well. Even so, some of our respondents had a positive opinion of the traditional lighting scene, thinking it was *"sensible and 'nice' (safe)"*, simply *"ok"* or that it *"improves visibility for the elderly"*. However, these opinions were in the minority, with most stating that they would prefer a different type of a lighting control method. Of all the participants, 28 % wanted to have this scenario as a permanent lighting solution.

Concerning *scenario 2*, (*"What do you think about this type of a lighting control method where the lighting is dimmed where there are no passers-by?"*) the responses were decidedly more positive. Several participants described the lighting control method in the scenario as *"good"*, *"very good"* or *"sensible"*, and many others still gave more in-depth positive answers: *"I think it's sensible to control lighting according to need"*; *"Good. It doesn't glare and it's better for the surrounding environment as well"*; *"Good idea, as long as it brightens when there's passers-by"*; *"Sounds logical"*. Several noted that it would save energy in their opinion. Some also had requirements for the system: Firstly, that the control method must function reliably. Secondly, that it would need to take into account all types of traffic, especially at a cross-roads or pedestrian crossing. However, some clearly dissenting voices were also expressed. One notable opinion was that scenario 2 was *"unnecessarily fancy"*. One other was concerned that it might add to feelings of unsafety. Others simply expressed negative opinions, stating that the scenario was *"not good"*, *"not nice"*, *"suspicious"* or *"bad"*. However, these were in the minority, and unfortunately, these negative opinions were also left unexplained. Of all the respondents, 45 % wanted to have the scenario 2 as a permanent lighting solution.

For our *scenario 3* (*"What do you think of a lighting control method like this where the lighting is dimmed where there are no passers-by, and the lighting is also controlled by the density of traffic?"*). Once again, the answers proved to be mostly positive. *"Best option"*, *"I support this [idea]"*, *"Good"* and *"Sounds good"* were common answers. Many participants also gave more detailed reasons: *"This is good too, why to light up empty roads." "Amounts of traffic do indeed vary a lot. It's more important to see further ahead during rush hour. Usually, light is needed more when there are more other road users."* One stated that it was a *"Good compromise between safety and energy consumption"*. Again, there was an important minority of negative opinions as well. Some expressed that it seemed difficult to understand, or that it was suspicious. Accurate sensing of passers-by was doubted by one participant. In general, fear of faulty operation seemed to be the most prevalent negative opinion. This is understandable from a commonsense point of view, as a more complex system can be seen as riskier. One also pointed out that more "moving parts" means more maintenance which might cost more. One laconically stated, *"As long as it works"*. 55 % of the participants accepted scenario 3 as a permanent lighting solution along the road, and 72 % either one of the scenarios 2 or 3.

At the end of the questionnaire, participants were asked how gaining more information about the lighting affected them. The overwhelming majority of opinions stated that it had a positive effect on them and that intelligent lighting control had even surprised them positively. One participant was frustrated that the information on the costs of devices was not available. We were surprised at how interested and motivated our participants were to learn more about street lighting control methods; however, it must be noted that participants had self-selected to participate. Nevertheless, there are many individuals with a desire for more knowledge on urban lighting among the general public.

4. Discussion and conclusion

The results of the real-world case study in Salo indicate that drivers' experiences of presence sensitive roadway lighting are at least as positive as the experiences of traditional, uncontrolled lighting concerning many factors which are essential from the perspective of traffic safety and visual comfort. These included the experienced uniformity of lighting on road surface, the experience of glare, and the visibility of road while driving. In addition, the presence sensitive lighting was experienced as being as pleasant as traditional lighting. In the statistical testing of the results with dependent samples t-tests no statistically significant difference between the two tested lighting scenarios was detected. However, concerning the visibility of other people moving on the road and in the surroundings, the test results indicated with slight statistical significance better results with presence sensitive lighting. One explanation for this surprising result might be the experienced focus effect as the illuminances were higher near the driver than in the far distance along the road. The results of the recent study of dimmed, static road lighting and car headlights [9] interestingly relate to this and open up new research questions and applications for presence sensitive and intelligent lighting. When the participants were asked specifically about negative experiences, almost the same percentage of them (19 % with the traditional lighting, 18 % with presence sensitive lighting) reported that something disturbed them. Interestingly, most of the drivers (at least 86 %) did not notice any dynamic change in lighting while driving along the test road. When informed about the tested lighting strategies, most of the participants (72 %) would prefer either one of the intelligent lighting modes to be the permanent lighting solution. The attitudes towards intelligent lighting were generally positive: it was deemed to be wise and modern solution – saving energy and costs, providing lighting when needed. While these results are extremely encouraging, they also warrant more research into the experienced safety and comfort of presence sensitive roadway lighting from different road users' perspective.

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