Work-related road safety: The impact of the low noise levels produced by electric vehicles according to experienced drivers

María del Carmen Pardo-Ferreira[a,*], Juan Carlos Rubio-Romero[a], Fuensanta Carmen Galindo-Reyes[b], Antonio Lopez-Arquillos[a]

[a] *School of Industrial Engineering, Universidad de Málaga, C/Dr. Ortiz Ramos s/n (Teatinos), 29071 Málaga, Spain*
[b] *Faculty of Commerce, Universidad de Málaga, Av. Francisco Trujillo Villanueva, 1 (Teatinos), 29071 Malaga, Spain*

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ABSTRACT

The introduction of electric vehicles in urban areas contributes to the reduction of air and noise pollution in these environments. However, the low noise levels produced by these vehicles, previously seen as an advantage, could pose a new risk to the safety of road users. The real magnitude of this issue is, however, controversial. The present study analyses the perception of experienced electric and hybrid vehicle drivers in work situations, something which had not been studied to date. A total of 95 electric car and motorcycle drivers from different public companies in the city of Málaga, Spain, participated in the study. These drivers described risk situations with pedestrians at low speeds, especially in shared streets. They estimated that the risk caused by the low noise levels of these vehicles is "medium". To compensate, many drivers stated that they are more alert while driving an electric vehicle. Additionally, the drivers suggested that equipping these vehicles with continuous external sound was not the most appropriate solution. In the scientific community there is no consensus on the best way to resolve this. Nevertheless, electric vehicles are now required to incorporate additional sound in the European Union and USA. This does not mean that this is a more effective solution. More research on this issue is thus needed, such as studying other non-acoustic solutions or analysing how other road users perceive the risk.

1. Introduction

The World Health Organization has identified air and noise pollution as the most significant environmental causes of ill health (World Health Organization, 2011). The most important source of noise pollution, measured in terms of number of affected people both inside and outside urban areas, is road traffic, which also contributes to higher air pollution (European Environment Agency, 2016). Consequently, the key goals in the European Commission's White Paper on Transport include halving the use of "conventionally-fuelled" cars in urban transport by 2030 and completely phasing them out in cities by 2050, to achieve essentially CO_2-free city logistics in major urban centres by 2030 (European Commission, 2017). Electric vehicles (EVs) play a key role in achieving these objectives. In fact, there are action plans that aim to promote the use of more environmentally friendly modes of transport, avoid increases in traffic flow and raise awareness of noise as an environmental problem (European Environment Agency, 2017). EVs are thus being supported by different strategies in Europe and also internationally. However, the low level of noise produced by EVs, which had previously been considered an advantage, is being questioned and could become a new safety risk for road users.

1.1. Research and regulations

Japan was the first country to consider the possibility that EVs could pose a risk to pedestrians (Ministry of Land, Infrastructure and Transport of Japan, 2006). However, the international controversy began when the United States National Highway Traffic Safety Administration (NHTSA) issued a report concluding that the incidence rate of pedestrian and cyclist crashes involving hybrid electric vehicles (HEV) was greater than for internal combustion engine vehicles (ICE) in certain manoeuvres, such as braking or stopping, backing up, entering or leaving a parking space or turning at very low speeds (Hanna, 2009). Other countries have conducted similar studies. The analysis of traffic crashes in Japan and the Netherlands did not show increased crash rates for HEVs compared to ICE vehicles (JASIC, 2009; Verheijen and Jabben, 2010). Although the UK study (Morgan et al., 2011) showed some results in line with the NHTSA study on incidence rates, it could not determine whether the noise reduction in HEVs was a contributing factor. The NHTSA results (Hanna, 2009) have been criticized because the report does not explain the extent to which the absence of hybrid engine noise is responsible for the higher number of pedestrian crashes. Nevertheless, governments worldwide have imposed regulatory speeds, and new regulations in the United States and the European Union propose that all EVs and HEVs must incorporate Audible Vehicle Alerting Systems (AVAS) at low speeds beginning in 2019.

The scientific community recognizes the possibility of problems or risks at speeds below 30 km/h, since at higher speeds tire noise on the road is greater and tends to mask the noise of the motor (Czuka et al., 2014; Garay-Vega et al., 2010; Mendonça et al., 2013; Misdariis and Cera, 2013; Morgan et al., 2011; Stelling-Kończak et al., 2016). At speeds below 30 km/h the HEVs operate in electric mode, so they would present the same problems as EVs. Sandberg (2012) states in practice that the noise difference between EVs and luxury ICE vehicles exists only at speeds below about 20 km/h. Several authors (Cocron and Krems, 2013; Sandberg, 2012) have criticised adding noise to vehicles as a solution and they point to the statistical weaknesses of the NHTSA study. Cocron and Krems (2013) stated that in a simple crash database it is almost impossible to determine whether the low noise emissions of these vehicles, or other factors such as inattention, caused the crash. These vehicles have existed for years on the roads and no one had noticed the problem, which suggests that a technological solution by itself may not solve the problem. Consequently, it is necessary to consider all of the possible solutions, even non-acoustic ones (Sandberg, 2012; Stelling-Kończak et al., 2016), which could improve the detectability of these vehicles while helping to improve noise pollution.

The studies carried out so far are based on the analysis of registered crashes and experiments conducted with pedestrians, especially the blind, in relation to the auditory detectability of vehicles, broken down by type (Czuka et al., 2014; Emerson et al., 2011; Garay-Vega et al., 2010; Stelling-Kończak et al., 2016). Drivers have the most experience regarding the interaction between pedestrians, cyclists and other vehicles, but few studies examine their perceptions. In Germany and Paris, two studies have been carried out, but with drivers that had no more than 6 months experience and less than 15,000 km behind the wheel (Cocron and Krems, 2013; Labeye et al., 2016). No studies have been found on the perception of experienced drivers that include driving during work or that include drivers of electric motorcycles.

1.2. Risk perception

Some authors define perceived risk as "the subjective evaluation by people of the risk they incur in a given situation" (Chaurand and Delhomme, 2013). In the field of road safety, according to Horswill and McKenna (2004), of all the different components of driving skill, only hazard perception or risk perception has been found to relate to crash involvement across a number of studies. Risk perception can be defined as "situation awareness for dangerous situations in the traffic environment" (Horswill and McKenna, 2004) Others such as Machin and Sankey (2008) indicated that risk perception, in relation to driving behaviour, refers to "the subjective experience of risk in potential traffic hazards" (Deery, 1999) and they considered it a precursor of actual driving behaviour. In that way, Groeger and Chapman (1996) claimed that tests of risk perception are worthy of close consideration since they are often considered to be one of the most promising techniques available for improving driver safety.

Different authors have analysed the factors or components that determine the risk perception of drivers (Brown and Groeger, 1988; Deery, 1999; Groeger and Chapman, 1996; Rundmo and Iversen, 2004). In the present study, we have focused on the components of risk perception proposed by Rundmo and Iversen (2004). They stated that to examine risk perception it is necessary to separately evaluate the cognitive or belief-based component and the affective or emotion-based component. They use a *Worry and Concern* scale to measure this affective component. The cognitive component focuses on the way drivers perceive and process information (Brown and Cotton, 2003; Deery and Fildes, 1999; Horvath and Zuckerman, 1992; Machin and Sankey, 2008; Sarkar and Andreas, 2004). Rundmo and Iversen (2004) analysed the cognitive component in the sense of probability of a crash. Similarly, other authors have used this approach (Cocron and Krems, 2013; Ma et al., 2010; Machin and Plint, 2010; Machin and Sankey, 2008; Taylor and Snyder, 2017). In fact, drivers' risk perception has been extensively studied. However, in line with the objective of the present study, as stated above, only two studies were found that analysed the risk perception of EV drivers in relation to the lack of noise (Cocron and Krems, 2013; Labeye et al, 2016). Cocron and Krems (2013) studied EV driverś perceived risk of being involved in critical incidents with other road users due to the low levels of noise produced by their EVs and how this perception changes over time. They concluded that concerns related to the low noise of EVs decrease over time. Similar results were obtained by Labeye et al. (2016), who indicated that silent operation would involve appropriate anticipated driving behaviours, that is, the drivers are aware of the low noise level of EVs and they modify their driving behaviour to prevent risk situations. In order to advance the research, the present study will analyse the perception of experienced drivers in an occupational setting.

The main objective of this paper is to determine the risk perception that experienced EV and HEV drivers at work have of the low noise level of EV and HEV cars and motorcycles in relation to road safety. The specific objectives are focus on determining:

- What is the *perception of experienced drivers* with respect to the low noise emission, but more specifically:
  - How drivers perceive the silent feature of EVs in general, that is, if it affects their behavior in driving, makes it difficult to detect or introduces a new risk.
  - Do experienced EV drivers consider low noise of EVs and HEVs as a safety road problem or as an improvement in driving comfort.
  - What is the risk perception of these drivers on the possibility of damaging other road users due to the low noise.
  - What is the level of risk to other users that they perceive due to the low noise.
- What *risk situations* they have experienced, that is:
  - How often other road users do not see or hear them and where.
  - What are the characteristics of dangerous situations or crashes that have experienced due to low noise.
- What are the *countermeasures* that they believe are necessary.

Based on the questions raised above, two hypotheses are formulated:

- H_1: The level of perceived risk due to low noise emissions of the electric vehicles is different according to whether the drivers were involved in incidents with these vehicles or not.
- H_1^*: The level of perceived risk due to low noise emissions of the electric vehicles is not different according to the type of electric vehicle used by the driver.

No specific hypotheses were made in relation to the types of risk situations experienced or possible countermeasures, as these research questions were exploratory in nature.

2. Materials and methods

This study was carried out during 2016 in the city of Málaga, which is located in Spain's Andalusia region. It is the southernmost large city in Europe and it lies on the Mediterranean Costa del Sol. Málaga covers a total area of over 395 km^2 and it is the sixth most populated city in Spain, the second largest in Andalusia, with a population of 570.006 inhabitants in the 2017 census. In demographic terms it is therefore larger than cities such as Lisbon, Dublin or Manchester.

Table 1
Distribution of items on the paper questionnaire administered to drivers in the second section of the interview.

Aspects evaluated	Description	No. Items	Likert Scale	Scores Likert Scale
Low noise level	Overall assessment of the influence of low noise levels on driving.	5	6 points	Scores ranged from 1 "very strongly disagree" to 6 "very strongly agree"
Safety concern	In relation to new hazards or risks arising from the low noise emission of electric vehicles.	3	6 points	Scores ranged from 1 "very strongly disagree" to 6 "very strongly agree"
Comfort	To evaluate if the low noise emission of electric vehicles increases comfort.	2	6 points	Scores ranged from 1 "very strongly disagree" to 6 "very strongly agree"
Cognitive component	The perceived likelihood of damaging other road users due to the low noise level of the electric vehicle.	2	7 points	Higher scores represented higher perceived crash probabilities due to low noise level
Efficacy	Perceived when driving an electric vehicle, in relation to the potential risks due to the low noise level, that is, their ability to compensate for this.	2	7 points	Higher scores represented higher perceived confidence in one's ability to account for potential risks
Affective component	The concern or worry of the drivers regarding the risk of causing injury to other users.	6	7 points	Higher scores represented higher perceived risk
Frequency	The number of situations in which the presence of the vehicles is not detected. A total of 7 different situations were included.	7	6 points	Scores ranged from 1 "never" to 6 "very frequently"

2.1. Procedure and materials

Hereinafter, when referring to EVs, the term includes both electric and hybrid vehicles in electric mode, that is, at low speeds. A structured interview was used to achieve the research objectives. The interview questions were designed using as the main sources the studies of Labeye et al. (2016) and Cocron and Krems (2013), who used the studies of Rundmo and Iversen (2004) and Machin and Sankey (2008) as a reference. Thus, the questions were translated and adapted to the specific characteristics of the participants: the use of vehicles while working and the use of electric motorcycles.

The data were collected through face-to-face interviews that took place at the collaborating companies. The interview included three sections. The first section collected the drivers' personal data, such as socio-demographic characteristics and driving experience. The objective of this section was to characterize the sample.

In the second section the drivers completed a questionnaire that contained 27 items, as shown in Table 1. It should be noted that Likert scales of 6 and 7 points were used because the original questionnaires also did so (Cocron and Krems, 2013; Labeye et al., 2016). This facilitates the future comparison between the studies. In addition, the percentage of "agreement" for each item of the 6-point Likert scale was included in the results. This percentage was calculated from the aggregation of the three upper values of the Likert scale (4-5-6) involving different degrees of agreement (Labeye et al., 2016). The main objective was to determine the perception of experienced drivers during the working day, with regard to the low levels of noise produced by electric cars or motorcycles and how frequently they experienced situations of risk.

In the third section, a semi-structured interview was conducted using questions that were designed from the sources described above. Its purpose was to identify and characterize possible crashes and risk situations that drivers had experienced due to the low noise produced by EVs when driving them. Finally, drivers rated the level of risk and the possible countermeasures that could be implemented. For this purpose, they had to assess the level of risk from 1 to 10, 1 being not dangerous at all and 10 very dangerous, and they had to distribute 100 points among different countermeasures that were proposed to them.

In addition, a brief summary of the study objectives was initially provided to drivers and the questionnaire included a space so that they could report any observations they considered significant. Nevertheless, they could expand their comments in the third section of the interview by talking to the interviewer.

During the interviews, the researchers provided the interviewed drivers with some clarifications on terms "incident" and "road users" in order to ensure everyone had the same definition. An incident was defined as a synonym of dangerous situation and road users were defined as anyone who used a road, such as a pedestrian, cyclists or other vehicles.

2.2. Participants and electric vehicles

The participants in this study were workers who drive EVs and HEVs, cars or motorcycles, during their working day. Most of them had been driving EV for at least one year. It is important to note that these workers are not professional drivers, that is, they are not truck drivers and their job is not to transport cargo or people. They use the vehicles during work to get around and they work in municipal companies that have EVs and HEVs in their fleets. These companies are responsible for the basic services provided by the city of Málaga, such as water, urban solid waste, street cleaning, the environment, public order and security. Therefore, they have to move around the city during the working day and they usually use EVs and HEVs. A total of 95 drivers participated in the study. The models of the vehicles that these drivers used were the electric car "Mitsubishi MieV", the electric motorcycle "Brammo Empulse" and the hybrid motorcycle "Piaggio MP3".

Table 2
Characteristics of the electric and hybrid vehicle drivers sample ($n = 95$).

Sample Characteristics	Variable		Cases	Percent
Socio-demographic characteristics	Gender	Male	90	95%
		Female	5	5%
	Age	Less than 25 years	0	0%
		25–34 years	7	7%
		35–44 years	47	49%
		45–54 years	31	33%
		55–64 years	9	9%
		Over 64 years	1	1%
	Occupational status	Director	5	5%
		Management Position	19	20%
		Technical Position	24	25%
		Operator	16	17%
		Police	31	33%
Driving experience	How long have you had your driving licence?	Less than 11 years	1	1%
		11–20 years	29	31%
		21–30 years	40	42%
		31–40 years	23	24%
		Over 40 years	2	2%
	Did you drive an electric vehicle before you started using it at work?	Yes	8	8%
		No	87	92%
	How long have you been driving an electric vehicle?	Less than 1 year	7	7%
		1 year	14	15%
		2 years	37	39%
		3 years	18	19%
		4 years or more	19	20%
	What type of electric vehicle do you drive during your working day?	Car	49	52%
		Motorcycle	35	37%
		Both of them	11	12%
	Do you usually use the electric vehicle every day during your working day?	Yes	40	42%
		No	55	58%
	How many hours a week is the electric vehicle in use during a working day?	Less than 10 h	41	43%
		11–20 h	14	15%
		21–30 h	7	7%
		31–40 h	2	2%
		Continuous use during the working day	31	33%
	In what environments do you usually travel with the electric vehicle?	Urban	68	72%
		Freeway or highway	1	1%
		Rural or county roads	0	0%
		Urban/Freeway or highway	20	21%
		Urban/Freeway or highway/ Rural or county roads	6	6%

The socio-demographic characteristics of the drivers who participated in this study are shown in Table 2. The majority were men between 35 and 54 years; only 5 women participated. Overall, the average age was 44.4 years. 45% of drivers occupied technical or management positions and 33% of drivers were police officers.

All drivers had held their driving licence for more than 10 years. Also, most drivers had not driven an EV before starting to use it at work. However, at the time of the interview, 78% of drivers had been using the EVs for at least two years. The results showed that 52% of drivers drove an electric car and 37% drove electric or hybrid motorcycles. Only 11% drove both a car and a motorcycle.

Although 58% of drivers reported that they did not use the vehicle every working day, 57% drove more than 10 h a week. Some had to provide services in the city streets and were constantly moving from one point to another. As a result, 33% of them stated that they used the EVs continuously. All of the drivers usually drove the vehicle in urban areas and 28% of them also drove on freeways or highways.

3. Results

3.1. Perception of experienced drivers with respect to the low noise emission

Table 3 presents the results for low noise, comfort and safety concerns. Nearly all respondents agreed that EVs are difficult to hear, and believed that this increased their comfort as vehicle occupants. However, across different items measuring safety concern, one-third to one half of respondents felt that low noise could pose a danger to other road users.

Table 4 presents the results for cognitive component, efficacy and affective component. More than half of the respondents considered that it was unlikely that other road users could be injured in a traffic crash due to the low noise level of EVs. In fact, one half of respondents thought they could minimize potential risk to traffic safety. In spite of that, almost half of respondents reported being concerned about the possibility that other road users would be injured by them or by other drivers.

3.2. Frequency of non-detection of the electric vehicle

In this part of the questionnaire, according to the procedure presented by Labeye et al. (2016), drivers were asked to indicate how often other road users did not see them or hear them, or saw them or heard them too late, in seven different manoeuvres or situations. According to Table 5, most drivers claimed that they were mostly not heard by other users when driving at low speeds, under 30 km/h, especially in vehicle parking areas. In addition, they indicated two manoeuvres in which they were not heard: when they turn and when the vehicle begins to move from a stationary position.

The manoeuvres or situations in which they were usually detected or heard were: while turning off the vehicle, while driving at speeds greater than 30 km/h or while parking. However, it should be noted that all manoeuvres or proposed situations obtained very close average scores, between 3.1 and 4.0.

3.3. Incidents due to low noise and possible countermeasures

According to Table 6, no driver reported that he had experienced a crash due to the low levels of noise emitted. Nevertheless, 62% of drivers interviewed described risk situations or incidents.

Most of the drivers stated that using the EV while they are working is an advantage. Also, about a third of drivers believed that the low noise of the EV is very advantageous because it makes driving more comfortable and less stressful. Some even indicated that adding noise to EVs is a step backwards. Moreover, some of them thought that it was necessary to increase pedestrian awareness so that this is not a problem in practice. In the case of drivers of electric motorcycles, some pointed out that when outside temperatures were very high, mainly in summer, driving an EV is an advantage, since it emits much less heat than an internal combustion vehicle. Driving regular motorcycles the whole working day caused some of them to have flushed skin, and with the electric vehicle this problem disappeared.

Finally, about one out of every three drivers indicated that they were clearly in favour of using EVs in general, not only at work. Among the other drivers, a large number said that they believed that the problem of the limited range and insufficient infrastructure for charging electric vehicles would need to be solved in order to ensure that electric vehicle are used in daily life and not only in the workplace. This explains the difference in the percentages between those who considered

Table 3
Results of drivers' responses to items related to Low noise level, Safety concern and Comfort.

	Items	Results of the answers Number/Percentage							
	Participants have to indicate their level of agreement with the following statements	Very strongly disagree (1)	Strongly disagree (2)	Mostly disagree (3)	Mostly agree (4)	Strongly agree (5)	Very strongly agree (6)	Percentage of agreement/ Margin of Error	Mean/ Standard Deviation
Low noise level	1. The electric vehicle is difficult for others to hear	4 4%	1 1%	7 7%	26 27%	14 15%	43 45%	87% 6.7	4.8 (1.3)
	2. The low noise of the electric vehicle is potentially dangerous	18 19%	7 7%	24 25%	31 33%	9 9%	6 6%	48% 10.0	3.3 (1.4)
	3. While driving the electric vehicle, I mostly had to get used to the lack of noise	29 31%	9 9%	26 27%	18 19%	6 6%	7 7%	32% 9.4	2.8 (1.5)
	4. I had to change my driving behavior due to the lack of outside noise of the electric vehicle	42 44%	17 18%	14 15%	16 17%	5 5%	1 1%	23% 8.5	2.2 (1.4)
	5. I would not mind if my electric vehicle had an idle noise so that others can hear me at any time (while standing, with engine on)	25 26%	12 13%	8 8%	23 24%	8 8%	19 20%	52% 10.0	3.4 (1.9)
Safety concern	6. I believe that the lack of noise from an electric vehicle is dangerous for road traffic	19 20%	8 8%	27 28%	29 31%	5 5%	7 7%	43% 10.0	3.1 (1.4)
	7. Even if an electric vehicle is harder to hear, other road users are not at higher risk	15 16%	7 7%	25 26%	26 27%	7 7%	15 16%	50% 10.1	3.5 (1.6)
	8. The lack of engine noise cause problems for other road users	29 31%	13 14%	19 20%	28 29%	3 3%	3 3%	35% 9.6	2.7 (1.4)
Comfort	9. The quietness of an electric vehicle is pleasing	4 4%	1 1%	3 3%	18 19%	18 19%	51 54%	92% 5.6	5.1 (1.3)
	10. The lack of engine noise of electric vehicles increases driving comfort	4 4%	3 3%	3 3%	14 15%	19 20%	52 55%	90% 6.2	5.1 (1.3)

Table 4
Results of drivers' responses to items related to Cognitive component, Efficacy, Affective component.

	Items	Results of the answers Number/Percentage								
	Participants have to report their perception using a Likert Scale. The meaning of the upper and lower value of the Likert scale are indicated between parenthesis in each item	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Not answer	Mean/Standard Deviation
Cognitive component	11. It is (very improbable/very probable) that I could injure other road users in a traffic crash due to low noise of an electric vehicle	26 27%	13 14%	18 19%	15 16%	10 11%	6 6%	6 6%	1 1%	3.2 (1.8)
	12. It is (very improbable/very probable) that electric vehicle drivers, in general, could injure other road users in a traffic crash due to low noise	25 26%	15 16%	15 16%	15 16%	13 14%	6 6%	6 6%	0 0%	3.2 (1.9)
Efficacy	13. I estimate that possibilities for me as an electric vehicle driver (do not exist/exist), to minimize potential risks to traffic safety related to low noise of an electric vehicle	11 12%	2 2%	4 4%	29 31%	14 15%	12 13%	21 22%	2 2%	4.7 (1.9)
	14. I think I possess (none of the necessary abilities/all of the necessary abilities), to minimize potential risks to traffic safety related to low noise of an electric vehicle	4 4%	1 1%	2 2%	16 17%	9 9%	28 29%	35 37%	0 0%	5.6 (1.6)
Affective Component	15. I feel (certain/very uncertain) that I could injure other road users in a traffic crash due to low noise of an electric vehicle	6 6%	7 7%	8 8%	16 17%	11 12%	19 20%	28 29%	0 0%	5.0 (1.9)
	16. I feel (certain/very uncertain) that electric vehicle drivers, in general, could injure other road users in a traffic crash due to the low noise	6 6%	8 8%	8 8%	17 18%	14 15%	22 23%	19 20%	1 1%	4.8 (1.8)
	17. I am (not at all worried/very worried) that I could injure other road users in a traffic crash due to low noise of an electric vehicle	29 31%	12 13%	11 12%	26 27%	8 8%	5 5%	4 4%	0 0%	3.0 (1.8)
	18. I am (not at all worried/very worried) that electric vehicle drivers, in general, could injure other road users in a traffic crash due to low noise	19 20%	12 13%	11 12%	22 23%	19 20%	6 6%	5 5%	1 1%	3.5 (1.8)
	19. I am (not at all concerned/very concerned) that I could injure other road users in a traffic crash due to low noise of an electric vehicle	16 17%	11 12%	5 5%	21 22%	16 17%	12 13%	12 13%	2 2%	4.1 (2.0)
	20. I am (not at all concerned/very concerned) that electric vehicle Drivers, in general, could injure other road users in a traffic crash due to low noise	16 17%	11 12%	6 6%	17 18%	19 20%	16 17%	9 9%	1 1%	4.1 (2.0)

Table 5
Results of drivers' responses to items related to the frequency with which the EVs are not heard in certain situations.

Items	Results of the answers Number/Percentage							
How often did other road users not see/hear you (or see/hear you too late) in the following situation?	It Never occurs to me that they do not hear me (that is, they always hear me) (1)	Very rarely (2)	Rarely (3)	Occasionally (4)	Frequently (5)	Very Frequently they don't hear me (6)	Not answer	Mean/ Standard Deviation
While starting the vehicle	13 14%	16 17%	13 14%	16 17%	18 19%	18 19%	1 1%	3.7 (1.7)
While turning the vehicle off	26 27%	19 20%	10 11%	9 9%	12 13%	17 18%	2 2%	3.1 (1.9)
While parking the vehicle	21 22%	16 17%	13 14%	12 13%	12 13%	20 21%	1 1%	3.4 (1.9)
While driving the vehicle < 30 km/h	10 11%	6 6%	12 13%	22 23%	31 33%	13 14%	1 1%	4.0 (1.5)
While driving the vehicle in > 30 km/h	16 17%	13 14%	17 18%	21 22%	19 20%	8 8%	1 1%	3.4 (1.6)
In vehicle parks	7 7%	13 14%	13 14%	25 26%	21 22%	14 15%	2 2%	3.9 (1.5)
By turning	7 7%	11 12%	22 23%	20 21%	25 26%	9 9%	1 1%	3.8 (1.4)

Table 6
Identification of crashes, incidents and assessment of the use of the electric vehicle as an advantage for all drivers ($n = 95$).

Description		Cases	Percentage
Have you experienced crashes?	Yes	0	0%
	No	95	100%
Have you experienced incidents?	Yes	59	62%
	No	36	38%
Is using electric vehicle during the working day an advantage?	Yes	77	81%
	No	18	19%

Table 7
Characterization of risk situations reported by drivers during interviews (n = 59).

Variable		Cases	Percentage
Manoeuvre in which they have experienced crashes or incidents	Less than 30 km/h	53	90%
	Traffic lights/turning	15	25%
	Overtaking/passing	6	10%
	Moving the vehicle from a stationary position/ parking areas	8	14%
	Straight ahead driving	11	19%
	Other manoeuvre	2	3%
Type of road user involved in the incident	Pedestrian	56	95%
	Cyclist	8	14%
	Motorcycle	6	10%
	Passenger of a car	0	0%
	Truck	1	2%
	Car	3	5%

that it was an advantage to use it in the workplace and those who were clearly in favour of a widespread use of this type of vehicles.

Table 7 summarizes the main characteristics of the risk situations or incidents obtained from descriptions by the 59 drivers who reported them. In relation to the manoeuvres that triggered these critical situations and the users involved, some drivers indicated more than one type of manoeuvre as risky or more than one type of user involved, since these questions were multiresponse.

Most of drivers who described risk situations reported that these had occurred at low speeds (< 30 km/h). This is in line with the results presented in the previous section, in which the drivers reported not being heard when driving at speeds under 30 km/h. Moreover, 25% of drivers indicated that they occurred at traffic lights or when turning and 19% of them said that they occurred when driving straight, in places such as streets in residential or urban areas where pedestrians crossed without looking.

Consequently, almost all drivers stated that the risk situations that they had experienced were with pedestrians. Most said that pedestrians were distracted and crossed without looking and, as they did not hear the vehicle, they did not notice their presence. One of the drivers said: "*In urban areas, where the pedestrian does not walk on the sidewalk, you have to be careful*". Other drivers reported similar problems with pedestrians due to traffic rules not being respected: "*The problem is not that the vehicle does not emit sound. People do not respect the pedestrian crossings and the pedestrians cross when the traffic light it is red for them because they do not hear a vehicle. They must look at the traffic light*". In that way, 59% of the risk situations occurred in pedestrian areas or shared streets. In this regard, drivers commented that when driving through areas shared with pedestrians, the latter very frequently did not notice the presence of the EV.

During the course of the interviews, they also pointed out other problems. Some drivers reported that some risk situations have occurred on company grounds due to the low noise levels of the EV. Specifically, one of them pointed out that "*the operators, when they saw that I was arriving, said 'give me a whistle or something'*". Lastly, other drivers indicated that they cannot honk the horn to warn of their presence, because it startles the pedestrians and they get angry.

Many drivers considered that their level of attention while driving an EV has changed compared to driving a conventional vehicle. Thus, most drivers said that they exercise extreme caution when travelling in an EV because they know that pedestrians do not hear them and are unaware of their presence. "*As a precaution, when I go through pedestrian zones I go very, very slowly*".

3.3.1. *Driver's perception of the level of risk*

The drivers assessed as "medium" the level of risk for other road users (e.g., pedestrians, cyclists, blind people, other drivers) for situations that could be generated by the low noise of EVs. In Fig. 1, the results of the responses of the grouped drivers have been collected according to the types of drivers, ie, drivers of cars, motorcycle drivers and drivers of both vehicles.

3.3.2. *Driver's perception of possible countermeasures*

Fig. 2 shows the assessment of the drivers of possible countermeasures that could be implemented.

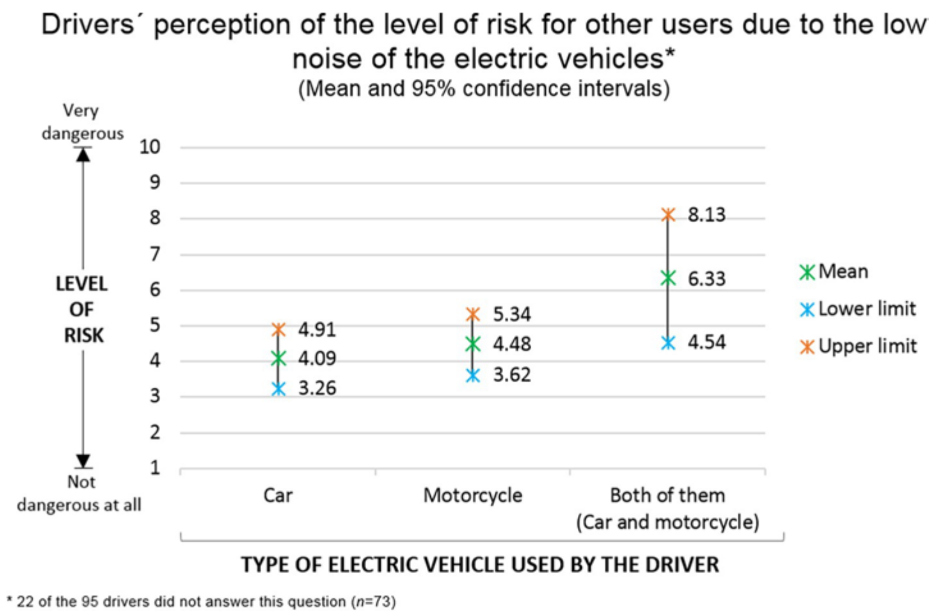

Fig. 1. Level of risk of situations that could be generated by low noise emissions of the electric vehicles assessed by drivers ($n = 73$).

3.4. Analysis of the hypotheses developed

Non-parametric tests were used to compare whether the perceived risk due to the low noise of EVs differed as a function of crash involvement or type of EV used. A Mann-Whitney test showed that perceived risk did not differ in drivers who were vs. were not involved in incidents, $U = 368.5$, $Z = -1.176$, $p = .239$. A Kruskal-Wallis test also showed that perceived risk was not significantly different when comparing drivers of different vehicle types (i.e., cars, motorcycles, or both), $H(2) = 5.023$, $p = .081$.

4. Discussion

Low noise emission is one of the new characteristics of EVs. It has been studied here with the aim of determining the perception of experienced occupational drivers. In general, it can be said that the results of the present study are in line with previous research (Cocron and Krems, 2013; Labeye et al., 2016). However, some differences in drivers' perceptions were found. These could be due to the different characteristics of our sample, such as experienced drivers, occupational scope, larger sample size and frequent driving through shared streets.

Regarding the results of Labeye et al. (2016), the number of drivers who confirmed that EVs are difficult to hear was much greater in our case. In fact, this was mentioned by the majority of respondents. This may be because our drivers sometimes drive on shared streets in the city centre, where pedestrians are not aware of the vehicles because they have the right of way. Also, fewer drivers reported that they had to get used to the low noise and change their driving behaviour. This difference may be due to the fact that 78% of drivers in this study have been driving EVs for two years or more. They thus adapted to driving these vehicles long ago and may not remember the adaptation period. In the case of Labeye et al. (2016), their sample consisted of new drivers of EVs and they may have been able to report the differences in driving more clearly because the experience was more recent. It should also be considered that the drivers in this study indicated in the interview that they are aware that other users do not hear them and pay more attention when driving. This implies that they have actually adapted their driving behaviour, even if they did not report it directly.

In relation to the study conducted by Cocron and Krems (2013), our drivers perceived that their capacity to compensate for the effects of the low noise of the EVs is slightly lower. In line with this, they reported that their safety concern is greater and, consequently, a notable

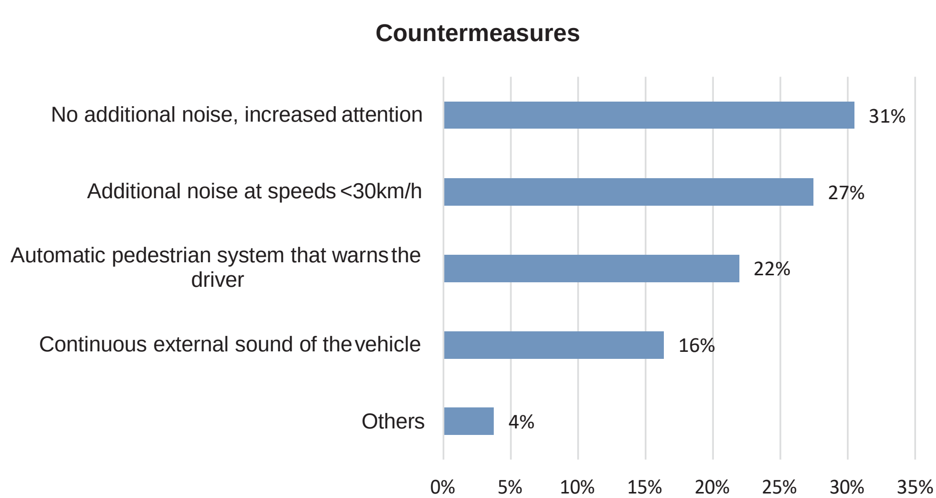

Fig. 2. Results of prioritization of possible countermeasures by drivers ($n = 95$).

increase in worry and concern for harming other users was recorded. Their perception of risks is probably higher because they sometimes drive through shared streets, as explained above. Nevertheless, it is necessary to emphasize that drivers were not very concerned, simply more concerned than drivers in other studies. In fact, no crashes were recorded since the drivers indicated that they know pedestrians cannot hear them and they drive more carefully. The likelihood of injuring other users received the same rating as reported by Cocron and Krems (2013).

As other studies confirmed, drivers may not be noticed in time by road users at speeds below 30 km/h, especially in parking lots, at crossings or exits (Verheijen and Jabben, 2010). According to the results obtained, this is when incidents usually occurred and the users most frequently involved were pedestrians. Regarding the level of risk perceived by drivers about these incidents or risk situations, no significant differences were found between two groups of drivers: drivers who reported having experienced incidents and those who reported not having experienced them. Although other authors such as Ngueutsa and Kouabenan (2017) found differences in the risk perception of drivers associated with crash history, in our case the results do not reflect these differences. Perhaps this is because the drivers who participated in this study had not been involved in crashes, only in risk situations. In addition, when the differences between the assessment of the level of risk by motorcycle drivers, car drivers or drivers of both types of vehicles was studied, no significant differences were found either. In summary, the results indicate that the level of perceived risk of situations that could be generated by the low noise emission of EVs is similar in drivers who were vs. were not involved in incidents or in drivers of different vehicle types. This level of risk was generally perceived as medium.

Another important point is the analysis of countermeasures or solutions that drivers consider necessary. Not adding sound and increasing attention was the countermeasure most valued by drivers, similar to the results obtained by Cocron and Krems (2013). Even the UK report (Morgan et al., 2011) pointed out that adding sound should be carefully considered, and that the first thing that should be done is an improvement in public awareness, as the magnitude of the problem is currently insignificant. As the Dutch report (Verheijen and Jabben, 2010) pointed out, adding sound to these vehicles and its impact on acoustic pollution must be considered, since it may have adverse effects on health. Therefore, studying alternative solutions was recommended, similar to what other authors report (Pardo-Ferreira et al., 2017; Sandberg, 2012; Stelling-Kończak et al., 2016). In addition, it is possible that in the presence of an artificial sound, drivers may expect vulnerable road users to be able to hear the car and therefore they may not drive as carefully as they would without the added sound (Sandberg, 2012). In spite of the above, regulations implemented by different governments have chosen the opposite solution, even though studies in various countries have not been statistically conclusive.

5. Conclusions

EVs are more difficult to hear for other road users, especially at low speeds and in urban environments. This entails a new risk for them, although it does not appear to be a risk of alarming magnitude. We must consider that the results of this and other studies suggest that drivers reported that they increase their attention to compensate for the low noise. Although this is a subjective opinion of the driver and it should be checked if this truly occurs, it seems likely that they could develop other driving behaviours aimed at compensating for the lack of noise. Perhaps it would be helpful to include training on this issue in driving courses. In the same way, other users could adapt their behaviour to this new scenario and technological solutions could be developed for those users with sensory deficiencies. In addition, even though drivers were concerned that other road users could be injured due to the low levels of noise, when they rated the countermeasures that should be implemented, it was found that the addition of a sound is not considered appropriate. Therefore, an additional sound might not be the best solution, especially, if it has a negative impact on attempts to reduce noise in cities and hence on the health of the population. However, the near future has already been decided and silent vehicles, such as EVs and HEVs, will mandatorily incorporate additional sound at low speeds. This does not mean that it is the most adequate way to deal with this new risk.

For this reason, more research on this issue is needed. Future research should aim to determinate the real magnitude of the risk and possible non-acoustic measures. In fact, it seems likely that a set of non-acoustical measures of a different nature, such as technology, awareness and education, may have a greater effect on risk mitigation than adding a sound, while favouring the reduction of acoustic pollution and increasing the quality of life in cities. Also, it could be helpful to analyse the risk perception of other road users such as pedestrians, cyclists, the blind, other internal combustion vehicle drivers or experts in the field.

Within the limitations of this study it should be noted that the size of the sample is not representative of the Spanish population, not even of the population of the city of Malaga. But it should be considered that the number of electric vehicles in cities is still small and even more so if we focus on the workplace. Thus, the findings of this study can help improve our understanding of the risk that could arise from the low noise levels of these vehicles. Regarding the limitations related to bias, there may be some kind of recall bias when thinking about risky situations with EVs. The drivers were asked about whether EVs might be dangerous because of low noise, what could prompt them to think about times when they had a near miss with a pedestrian, but they had similar experiences with ICE vehicles that they had not thought about in the same way. It is also difficult to know if these situations occurred due to lack of noise or due to other causes such as distractions. In addition, a response bias could exist for others reasons: the length of the survey and the subjective perception of risk. Therefore, in order to increase the probability of collecting reliable responses, face-to-face interviews are considered the most appropriate method for data collection. However, we have to consider that the conclusions about the perception of drivers of low noise levels are based on self-reported behaviours and opinions. Similarly, if participants report their adaptive behaviours, we do not have any objective measurements to confirm that they do this or, if they do, that is adequate compensation. In order to provide more objective measurements, the authors are developing two more studies focused on the perception of pedestrians and experts in the field.

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