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Acoustic Vehicle Alerting Systems (AVAS) of electric cars and its possible influence on urban soundscape

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ABSTRACT

Starting July 1, 2019, all new types of hybrid electric and pure electric vehicles in the EU must be equipped with an Acoustic Vehicle Alerting System (AVAS), in particular to warn pedestrians at low driving speed. In a case study, comprehensive measurements of the pass-by levels on 7 current electric vehicles were carried out at constant pass-by speeds of 10 km/h to 50 km/h. This involved recording the sound pressure level including and without AVAS. The results show that in some cases the pass-by level is considerably increased by the AVAS. Due to the frequently low speeds in urban traffic, the AVAS will play a relevant role for the future acoustics and soundscape of cities. On the one hand, electric vehicles generally induce less noise in urban traffic than vehicles with combustion engines – a chance to reduce health threatening urban environmental noise. However, since the AVAS of electric vehicles is intended to attract attention for safety reasons, it can on the other hand also generate additional noise annoyance. Considering an increasing share of electric vehicles in urban traffic in the future, the effects on urban soundscape and the quality of life are investigated.

Keywords: Electric vehicles, Acoustic Vehicle Alerting Systems (AVAS), Soundscape, Quality of life

1. INTRODUCTION

Road traffic is the main source of noise, especially in urban areas, and often exposes people to high noise levels. In the European Union by itself, an estimated 125 million people are exposed to road traffic noise levels above 55 dB(A) L_{den} (day-evening-night level) (1), which, according to the current Environmental Noise Guidelines of the World Health Organization, can increase noise-induced health impairments, such as the risk of ischemic heart disease (2). According to the guidelines, the risk of adverse health effects is even increased from a level of road traffic above 53 dB(A) L_{den}. Noise pollution and the associated impairment of quality of life cannot be ruled out even far below these levels (2). In a survey on quality of life with around 37,000 participants in 33 European countries, around a third of respondents felt annoyed by noise in their neighborhood. In cities and urban areas, up to half of the respondents reported noise problems impairing their quality of life (3).

Since the actual noise impact and annoyance cannot be fully explained by physical measurement and forecasting techniques, an integrated approach to noise assessment is often called for (4). The soundscape approach provides an opportunity to extend the classical noise assessment methods by focusing on the perception of the acoustic environment by the exposed persons (5). In recent years, a standardized framework has been developed to support a general understanding of soundscape and the practical application of the concept (6, 7).

Since vehicles with electric motors are generally much quieter at low speed than vehicles with combustion engines (8, 9), there is a relevant noise reduction potential, especially in urban traffic. The low noise emissions from electric vehicles can, however, endanger the safety of pedestrians and cyclists, especially at low speed, as the vehicles are less well perceived. This can be dangerous for example for blind people (10, 11).

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For this reason, in accordance with the ECE regulations (for the European Union and other countries) as well as the technical regulations of the NHTSA (USA) for hybrid electric and purely electric passenger cars, there will be a requirement to install an Acoustic Vehicle Alerting System (AVAS) in the future (12, 13). Differences in the regulations of the NHTSA and the ECE are compiled in a publication by Wagner and Gajda (14). According to ECE Regulation No. 138, vehicles must emit a minimum sound level from motion up to a speed of 20 km/h. A frequency shift must take place to make the acceleration and deceleration of the vehicle audible. The AVAS must not exceed a defined maximum level. Thus the vehicle may only be as loud as the lowest permissible limit value for vehicles with combustion engine (12). Many e-vehicles currently have the option of temporarily switching off the AVAS via a switch in the interior of the vehicle (pause function). When the vehicle is restarted, the AVAS is automatically reactivated. This option will no longer be available in the future (15).

At present, there are many e-vehicles that are already equipped with an AVAS. The AVAS causes additional noise emissions that can change the acoustic environment. There is a dilemma here between the perceptibility of warning signals to ensure safety and potential annoyance from artificial sounds.

2. INVESTIGATION OF NOISE EMISSIONS FROM ELECTRIC CARS

So far, there are only a limited number of studies that address the noise emissions of electric cars at low speed and the possible effects on urban soundscape and quality of life. There are certainly many studies that investigate the noise emissions of electric cars in comparison to cars with internal combustion engines (9, 10, 16, 17). However, the effect of acoustic warning systems on the environment was still not the focus of these studies.

In general, the total noise of passing vehicles in city traffic is composed of the powertrain and tire/road noise. In theory, at low speed the noise of the powertrain dominates, while at higher speed the tire/road noise is decisive (18). For electric cars, the powertrain noise contributes only slightly to the total noise level. In a study investigating the rolling noise of electric car tires, the rolling noise was the main sound source even at a low speed of only 20 km/h (19). Here, however, there was no influence from AVAS.

We assume that the AVAS will significantly increase the noise emissions of electric cars at low speeds and that this will have an impact on the urban soundscape and the quality of life. The present study therefore examines the pass-by levels of electric cars at low speeds. The noise emissions of passing vehicles at constant speed with and without AVAS are compared and evaluated. The first question here is to what extent the AVAS increases the pass-by level of vehicles. Subsequently, possible effects of AVAS on noise pollution, urban soundscape and quality of life will be discussed. Based on the previous knowledge and the factual context, findings on the possible influence of AVAS on urban soundscape and quality of life conveyed by noise pollution are finally derived.

3. METHODOLOGY

3.1 Sound measurements on electric cars

In order to investigate the noise emissions of electric cars, noise measurements were carried out on 7 pure electric cars. The noise measurements on the vehicles were carried out during pass-by at a constant speed between 10 km/h and 50 km/h. Since the AVAS only generates noise in the speed range from the movement of the vehicle up to a maximum of 30 km/h, in the present case a focus was placed on driving speeds up to 30 km/h. Almost all the studied cars were already equipped with an AVAS. If the AVAS could be switched off by the driver in the vehicles, the pass-by levels including and without an AVAS were recorded. In this way, the acoustic contribution of the AVAS to the overall noise level can be determined. Table 1 below lists the electric cars that were studied. In addition, it is described whether the vehicle is equipped with an AVAS and whether the AVAS can be manually switched off by the driver.

Table 1 – Studied electric cars

Studied vehicle (manufacturer and model)	Vehicle equipped with AVAS	AVAS in operation (from the movement of the vehicle to a speed of approximately)	AVAS can be switched off by the driver
Hyundai Ioniq	yes	25 km/h	yes
Opel Ampera	yes	23 km/h	yes
Nissan Leaf	yes	30 km/h	yes
Tesla Model S	no	-	-
Smart Forfour	yes	30 km/h	no
Renault Zoe	yes	30 km/h	yes
VW e-Golf	yes	30 km/h	yes

The e-cars were mainly current models (first registration in 2016 to 2018), with a low mileage (average approx. 16,000 km). With the exception of the VW e-Golf, which was fitted with winter tires, all of the other cars were fitted with summer tires. The tires of the vehicles (nominal width/height to width in mm) ranged from 185/60 mm (Smart Forfour) to 245/45 mm (Tesla Model S).

3.2 Conducting and analyzing the sound measurements

The measuring arrangement for the recording of the pass-by levels was carried out in accordance with the requirements of Regulation (EU) No. 540/2014 (20). The sound pressure level (L_{AFmax}) at a distance of 7.5 m from the center axis of the vehicle was measured at constant speeds of 10 km/h, 20 km/h and 30 km/h on the left and right sides of the vehicles. The sound measurements per speed and situation were carried out for at least 6 vehicle passes, so that at least 12 sound measurements were carried out for each speed.

The measurements were carried out on a minor road with a low background noise level in August and November 2018. The pass-by levels of the vehicles studied (L_{AFmax}) were at least 10 dB(A) above the background noise level ($L_{AF95\%}$) on each of the measurement dates. A relevant influence of background noise on the sound measurements can be excluded in this case. The noise measurements on the vehicles at a constant speed of 10 km/h represented an exception. In this case, the pass-by levels of the studied vehicles were still at least 7 dB(A) above the background noise level, so that no relevant influence on the pass-by level can be expected in this case as well. However, this is an acceptable value for sound measurements on electric cars. In comparable studies, the noise measurements on electric vehicles at low speeds were only rejected if the noise level during pass-by was less than 3 dB(A) above the background noise level. (17). No background noise correction was performed.

The surface course of the road at the measuring site consisted of asphalt concrete (AC) with a grain size of 0/11 mm. All measured values were used in the evaluation of the measurements. Only measurements that were obviously influenced by disturbances (levels not caused by the passing of the vehicle) were not taken into account for the evaluation. For each vehicle and speed, the arithmetic mean of the pass-by levels was calculated. In the evaluation of the measured values (L_{AFmax}), the variance per vehicle and speed was usually approximately 1 dB(A), in rare cases up to 2 dB(A).

4. RESULTS

The following table compares the sound pressure levels (SPL) during pass-by of the electric cars examined at 10 km/h, 20 km/h and 30 km/h with and without AVAS. For the sake of clarity, the values listed in the table were rounded off to whole numbers. The differences of the pass-by levels including and without AVAS were, however, calculated from the non-rounded arithmetic mean of the measured values.

Table 2 – 7.5 m pass-by level (L_{AFmax}) of the e-vehicles including and without AVAS in dB(A)

Studied vehicle (manufacturer and model)	SPL including AVAS (at 10/20/30 km/h)	SPL without AVAS (at 10/20/30 km/h)	Difference in SPL including and without AVAS (at 10/20/30 km/h)
Hyundai Ioniq	49/56/60	43/54/60	6/2/0
Opel Ampera	49/52/57	42/51/58	7/1/0
Nissan Leaf	47/52/58	44/52/58	3/0/0
Tesla Model S	-	46/56/62	-
Smart Forfour	45/53/59	-	-
Renault Zoe	54/58/60	43/53/60	11/5/0
VW e-Golf	50/57/62	50/56/62	1/1/0

It can be seen that the pass-by levels of electric cars caused by the AVAS sometimes increase significantly, especially when passing by at 10 km/h. When driving past at 20 km/h, the level increase is less distinct, but is still present, whereas when driving past at 30 km/h, no relevant level increase is detected by the acoustic warning system in any of the studied vehicles. The level increase due to the AVAS is very variable. While the acoustic warning system increases the pass-by level of the Renault Zoe by 11 dB(A), the AVAS only increases the level of the VW e-Golf by 1 dB(A). Correspondingly, the acoustic warning system of the vehicles is designed very differently by the manufacturers.

The pass-by levels including AVAS were sometimes very different on the left and right side of the vehicle. The investigated Renault Zoe represents an extreme case. Here, differences in the pass-by levels of 7 dB(A) and 4 dB(A) were determined between the left and right sides of the vehicle at 10 km/h and 20 km/h, respectively. Wagner and Gajda suspect that higher levels than necessary will be induced on certain sides of the vehicle if only one speaker is installed for the warning signal and manufacturers are required to comply with the AVAS minimum sound pressure level on all sides of the vehicle (14).

In addition to the increase in the sound pressure level, the evaluation of artificial noise by other road users such as pedestrians or residents plays a decisive role. In order to investigate the possible effect of AVAS on urban soundscape and quality of life, existing studies on the perception of acoustic warning systems will be summarized in the following. Based on the previous knowledge and the factual context, findings on the possible influence of AVAS on urban soundscape and quality of life conveyed by noise pollution are finally derived.

5. DISCUSSION

5.1 AVAS - potential conflict between safety and annoyance

The measurements on the sample of electric cars show that the AVAS can significantly increase the pass-by level in certain cases. Basically, this leads to a conflict between the desired traffic safety and a possible noise annoyance caused by artificially generated sounds.

Already in 2010, Giudice et al. pointed out that artificial sound from electric vehicles could be annoying, impair the soundscape and quality of outdoor living (21). According to Genuit and Fiebig, noise can be particularly annoying if it is perceived as unnecessary. Especially in the case of artificially generated warning signals from electric vehicles, noises might find little acceptance. In addition, the overlaying of warning noises could create an annoying acoustic environment (22). Thus Genuit and Fiebig describe that the influence on environmental noise is often not fully taken into account in the development of warning signals for electric vehicles. In particular, aspects of perception and annoyance caused by multiple vehicles with warning signals are generally not taken into account (23).

A study on the annoyance of AVAS showed that both the individual pass-by of an electric car with AVAS and the pass-by of several electric cars with AVAS were perceived by the study participants in listening experiments as being considerably more annoying than the pass-by of cars with a combustion engine. Steinbach and Altinsoy suspect that this may be due to the fact that participants are familiar with the sound of cars with internal combustion engines, while the artificial warning signals of e-cars were probably previously unknown among the participants (24). Similar findings were obtained in a listening experiment study on the detectability and annoyance of various warning signals from Parizet et al. Some warning signals were perceived as annoying as the noise of a diesel car passing by. Here it was also shown that the recognition of a warning signal strongly depends on the timbre, but not on the total sound pressure level (25).

In addition to the annoyance for the environment, the warning signals, according to Wagner and Gajda, can also be perceived as annoying by the driver, since the vehicle can no longer be moved silently and the artificial noise is added inappropriately to the vehicle's own noise. The driver often has reservations about disturbing the quiet environment with artificial noise, which is why the noise is often paused manually by the driver directly after starting the vehicle (14).

5.2 Possible consequences for urban soundscape and quality of life

The described studies on the perception of AVAS in electric vehicles suggest that artificial sounds of electric vehicles may influence the soundscape in cities and consequently may become a noise annoyance in the future. The much-discussed and aspired urban quality of life could thus be further restricted. The soundscape concept represents an interdisciplinary, holistic approach in which the perception of the acoustic environment by the exposed is the main focus. Basically, a distinction is made between the perceptual construct (soundscape) and the physical phenomenon (acoustic environment). The soundscape is (only) created by the human perception of the acoustic environment (6). For example, the effect of an acoustic environment on well-being and quality of life can also be addressed. Data acquisition in soundscape studies should take place, for example, through sound walks, questionnaires, guideline-based interviews and binaural measurements. Ideally, the data should be collected on site. According to ISO/TS 12913-2:2018, each soundscape study should always consider the key components of the user, acoustic environment and context (7).

Since the share of e-cars with AVAS in total traffic is still relatively low at the moment and the total noise level in cities is usually dominated by the noise of vehicles with combustion engines, it is currently difficult to conduct soundscape studies in an acoustic environment that is influenced to a sufficient extent by AVAS. In soundscape studies with the simulation of acoustic environments and the execution of listening experiments, immersive methods should be taken into consideration when playing back via speakers or headphones (7).

When considering the influence of AVAS on the acoustic environment and the soundscape, it is therefore inappropriate to derive generally valid conclusions, since the individual situation should be taken into account with the involvement of the exposed. From the previous knowledge and the factual context, however, the following findings can be derived on the possible influence of AVAS on soundscape and quality of life conveyed by noise pollution.

Since the AVAS is only operated at low driving speeds up to a maximum of 30 km/h, an influence on the urban soundscape can be assumed, especially in certain traffic situations such as stop-and-go traffic, in residential areas or on minor roads. However, the possible influence is essentially limited to these situations, as the AVAS is masked by tire-road noise at higher driving speeds (14). Basically, however, it is precisely these traffic situations and the acoustic environments in which e-vehicles offer the greatest noise reduction potential compared to vehicles with internal combustion engines that are affected by potential noise pollution from the AVAS.

A possible influence on the urban soundscape and an annoyance potential by the AVAS is given if the total noise level (from other road traffic or other sound sources) is particularly low.

The personal attitude of the exposed to the sound source is relevant for the perception and evaluation of sound effects and should be considered in AVAS soundscape studies. One study, for example, found that people with a positive attitude towards air traffic (objectively) had less sleep disturbances caused by aircraft noise (26). It can be assumed that a generally positive attitude of exposed persons towards e-mobility influences the evaluation of the sound effects from the AVAS. In addition, noise annoyance and disturbance assessments may be influenced by other factors related to road traffic, such as traffic-related air pollution (27). Furthermore, changes in the assessment of vehicles as status symbols can play a special role, especially for the younger generation (28).

If the exposed are not familiar with the noises of the AVAS, it is possible that the noises of the AVAS are perceived as equivalent (25) or more annoying (24) compared to the noises of vehicles with combustion engines.

An exclusion of vehicles with combustion engines in a city district or the redesign of a city district in which only e-vehicles are allowed to drive can represent a targeted design of an acoustic environment characterized by noises from AVAS. It can be assumed that the inclusion and information of the exposed increases the acceptance of the sounds.

Soundscape studies on the effects of AVAS can provide in-depth knowledge on potential effects on the quality of life conveyed by noise pollution, particularly as there is a continuing need for in-depth research in this area. In a systematic review, Clark and Paunovic examined 14 quantitative studies on the link between road traffic noise and self-reported quality of life or health. Clark and Paunovic concluded that there is a very low evidence that road traffic noise has no relevant effect on the self-reported limitation of quality of life or health. The very low evidence of the assessment can be explained by the fact that there are too few studies in this field of research and that, in particular, suitable intervention and cross-sectional studies are lacking. The lack of evidence, however, does not necessarily mean that there are no effects, but that the complex interrelationships have not yet been investigated sufficiently (29).

Should it turn out in the future that the acoustic warning systems of electric vehicles have a negative impact on urban soundscape and quality of life, the question arises whether road safety cannot be ensured in another way. There may also be other appropriate methods to warn the blind about quiet electric vehicles. Thus, according to Yamauchi, the problem is defined less by the silence of the e-vehicles than by the existing environmental noise. Forcing a quieter urban environment would make it easier to hear the quiet vehicles better. Enforcing stricter noise emission standards for vehicles would be beneficial not only for the visually impaired or the elderly with impaired hearing, but also for residents (30).

6. CONCLUSIONS

In the present study, the pass-by levels of a sample of electric cars including and without AVAS were recorded and the potential effects on urban soundscape and quality of life were discussed. The results of the case study show that the acoustic warning system can considerably increase the pass-by level of e-cars, especially at low speeds, but that the AVAS level increase varies considerably depending on the vehicle. The AVAS increased the pass-by level from 1 dB(A) to 11 dB(A) depending on the vehicle. When passing electric cars at 30 km/h with and without AVAS, no level difference anymore was determined.

Regarding the possible influence of AVAS on urban soundscape and quality of life conveyed by noise pollution, it can be stated that it is precisely the traffic situations and acoustic environments in which electric vehicles have the greatest noise reduction potential compared to vehicles with internal combustion engines (low driving speeds and low background noise levels) that are affected by a possible noise annoyance by AVAS. It cannot be excluded that the sounds of AVAS will be perceived to be more annoying than those of vehicles with combustion engines. Ultimately, it is conceivable that the overlay of AVAS by varying tone pitches and tone durations can lead to a cacophony that leads to a disharmonic urban soundscape that disregards listening habits.

The urban soundscape approach provides a suitable tool to gain basic knowledge for planning and designing acoustic environments and to improve the quality of life. With a fundamental change in transport systems expected in the future, the opportunity should be seized to actively design acoustic environments. Urban soundscape approaches are conceivable, whose basic considerations also include a still to be determined harmony of the AVAS in concept and planning.

Should there be more evidence in the future that the acoustic warning systems of e-vehicles can be expected to have relevant negative effects on urban soundscape and quality of life, the question arises whether road safety cannot be ensured by other means. In the targeted design of acoustic environments, it is of particular relevance how the noises of electric vehicles harmonize with the environment (28) without endangering road safety and impairing the quality of life of residents. The proportion of electrically powered vehicles could rise significantly in many parts of the world in the coming years. Accordingly, the acoustic effects of an increasing share of electric vehicles in total traffic must also be investigated.

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