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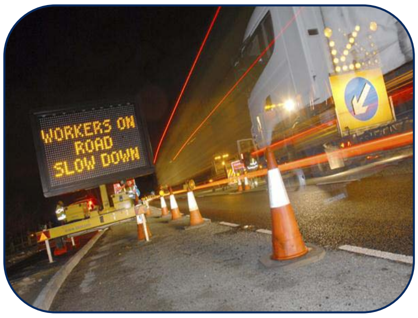

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Assessing the perceived safety risk from quiet electric and hybrid vehicles to vision-impaired pedestrians

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Executive summary

Over 90% of the UK population hears traffic noise at home and approximately 10% regard this exposure as highly annoying. The Environmental Noise Directive 2002/49/EC aims to prevent/reduce environmental noise from sources such as road traffic where necessary and preserve noise quality where it is good. Potential mechanisms for achieving this include the increased use of quieter vehicles (through reduced powertrain and tyre noise) and low-noise road surfaces. One option for quieter vehicles is the use of vehicles powered by electric motors, either fully electric or hybrid electric vehicles (E/HE).

In response to issues such as carbon reduction and as part of a drive towards cleaner fuels, the Department for Transport (DfT) is actively supporting use in the UK of low CO_2 vehicles, which are primarily E/HE vehicles.

However, groups representing the vision-impaired, both in the UK and internationally, have raised concerns that, due to their low noise, such vehicles may pose an increased accident risk to vision-impaired pedestrians.

DfT has commissioned TRL to investigate the accident risk posed by E/HE vehicles and compare it with that for equivalent vehicles with traditional internal combustion engines (ICEs), and to determine whether E/HE vehicles are audibly more difficult to detect.

This report presents the findings from the study, based upon a review of vehicle accident statistics, a programme of practical measurements to compare the noise of E/HE and ICE vehicles, and a small-scale subjective assessment of the noise from these vehicles involving vision-impaired participants.

An analysis of vehicle accident statistics for Great Britain has been undertaken for the period 2005-2008 and shown that:

- *Relative to the number of registered vehicles*, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were 30% less likely to be involved in an accident than ICE vehicles (495 accidents compared to 737,655). Introducing vans < 3.5 tonnes Gross Vehicle Weight (GVW) into the vehicle group, then E/HE vehicles were 38% less likely to be involved in an accident than ICE vehicles (497 accidents compared to 782,355)
- *Relative to the number of registered vehicles*, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were equally as likely to be involved in a collision with a pedestrian as ICE vehicles (61 accidents compared to 63,575). Introducing vans < 3.5 tonnes GVW into the vehicle group, then E/HE vehicles were 10% less likely to be involved in a collision with a pedestrian than ICE vehicles (62 compared to 67,610)
- While the relative rates are all less than one, comparing the relative rate for E/HE vehicles involved in all accidents (0.62) with the relative rate of E/HE vehicles which collide with a pedestrian (0.90) suggests that although the relative number of E/HE vehicles involved in accidents is smaller, proportionately more of these vehicles hit a pedestrian than ICE vehicles. Considering the combination of passenger cars and car-derived vans only, the relative rates are 0.70 and 1.0. Whilst this potentially supports the perceived increase in pedestrian risk for E/HE vehicles, it may be that the accident rates reflect the usage patterns of E/HE vehicles; total mileages for E/HE

vehicles may be lower than ICEs hence the lower overall accident rate, but a higher proportion of their use may be in urban areas, hence the similar pedestrian accident rate to ICEs

- There were only two E/HE accidents involving a collision with a pedestrian who was disabled in some way (CF810) so it is not possible to make a judgement on the perceived risk to vision-impaired pedestrians
- However, none of the relative rates take account of vehicle speed, vehicle manoeuvre or the location of the accident, e.g. whether or not the accident occurred in a built-up area. Additionally, no differentiation is made between fully electric and hybrid electric vehicles
- Considering only passenger cars and car-derived vans, the majority of accidents in which vehicles collided with pedestrians occurred where speed limits are 30 mph or less regardless of vehicle powertrain type (93.4% for E/HE vehicles and 91.4% for ICE vehicles). It was not possible to determine the speed of the vehicles at the time of the accident and as such it is unknown whether hybrid vehicles were operating in full electric mode at the time of the accident. Furthermore, it cannot therefore be determined whether a lack of noise from E/HE vehicles was a contributory factor in the accident
- The E/HE vehicle dataset was too small to allow a more detailed, meaningful assessment of the accident statistics in terms of parameters such as location (at or away from junctions and the availability of pedestrian crossing facilities) and vehicle manoeuvres

A test programme of practical measurements was conducted on four conventional vehicles and four E/HE vehicles performing different manoeuvres at a range of speeds to assess the noise generated. The results showed that

- When travelling at low steady speeds (7-8 km/h), the E/HE vehicles were, on average, 1 dB(A) quieter than the ICE vehicles. It is noted that at these speeds, the vehicles were typically 3 dB(A) above the background noise level. An increase in level of 3 dB(A) will be detectable by an adult with normal hearing.
- At low steady speeds, one of the ICE vehicles was at least as quiet as the E/HE vehicles
- Under faster steady-speed conditions (20 km/h and above) noise levels for the different vehicle types were, on average, similar as tyre/road noise becomes the dominant noise source.
- When pulling away from stationary, overall noise levels for the different vehicle types were similar, however the results show that E/HE vehicles can, over the initial period of acceleration, be marginally quieter than their ICE counterparts but after the first 5m both vehicle types have broadly similar noise levels
- Other than peaks in the pass-by noise spectra related to exhaust noise, there does not appear to be any significant difference in the acoustic signature of ICE and E/HE vehicles, and as such nothing that suggests a pedestrian would clearly be able to differentiate between vehicle types

Subjective audio assessments of E/HE and ICE vehicles performing a range of manoeuvres were conducted with 10 vision-impaired participants, although these were not 'representative of that part of the population suffering visual impairment'. Results were considered in terms of "risk exposure", based on the assumption that there will always be some element of risk, however small, for crossing pedestrians whenever traffic is present on the road. Risk exposure was deemed to be 'increased' if the presence of the vehicle was detected at a distance less than typical safe stopping distances or not detected at all.

- Although conclusions cannot be drawn that represent the situation at a national level, the subjective test results showed that in a semi-rural environment, the likelihood of increased risk exposure was 1.4 times greater for E/HE vehicles than for ICE vehicles. In urban conditions, the likelihood of increased risk exposure was 1.3 times greater for E/HE vehicles than for ICE vehicles (due to the reduced detectability of quieter ICE vehicles). The E/HE vehicles were far more difficult to detect than the ICE vehicles at the lowest steady speed and when pulling way from rest at the lowest speed

With further technological changes in engine design, particularly related to ICE vehicles, any future move to increase the audibility of E/HE vehicles at low speeds to address public concerns may also potentially have to take into account future model 'quiet' ICE vehicles.

Careful consideration will be required if 'added sound' is to be used to improve the audibility of quiet vehicles. This will need to take into account the environments under which the vehicle is being used, the low speeds and the differing levels of background noise that might have to be overcome to prevent masking the audibility of the vehicle. This therefore makes moves to impose minimum noise limits on vehicles challenging.

Improving public awareness of all quiet vehicles, both E/HE and ICE, in both pedestrians and drivers may be a first step in reducing perceived risk.

A further investigation of the available accident statistics is recommended which should consider quiet ICE vehicles as either an individual subset or in combination with E/HE vehicles. These statistics will not determine whether the potential reduced noise from quiet ICE vehicles is a contributory factor, but they will provide a greater indication of the potential risk from such vehicles.

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1 Introduction

Over 90% of the UK population hears traffic noise at home and approximately 10% regard this exposure as highly annoying. The Environmental Noise Directive 2002/49/EC (European Commission, 2002) aims to prevent or reduce environmental noise from sources such as road traffic where necessary, and preserve the noise quality where it is good. Potential mechanisms for achieving this include the increased use of quieter vehicles (through reduced powertrain and tyre noise) and low-noise road surfaces.

One option for quieter vehicles is the use of vehicles powered by either fully electric or hybrid electric (E/HE) engines. Based on current international strategies and public attitudes towards more energy-efficient and sustainable transport systems, it is foreseen that the use of E/HE vehicles is likely to increase in the future.

In response to issues such as carbon reduction and as part of a drive towards cleaner fuels, the Department for Transport (DfT) is actively supporting use in the UK of low CO_2 vehicles, which are primarily E/HE vehicles, via grants to reduce the upfront purchase costs to consumers.

However, groups representing the vision-impaired, both in the UK and internationally, have raised concerns that, due to their low noise, such vehicles may pose an increased accident risk to vision-impaired pedestrians, who rely on audible environmental cues to assist with their mobility and orientation. Vehicle engine noise helps to provide an indication of speed, behaviour (steady speed movement, acceleration or deceleration) and proximity. As such, the sound of approaching traffic, or rather the absence of this sound, provides a cue that can be used to assess when it is safe to cross the road or avoid cars manoeuvring in a car park.

These concerns have been reflected in questions to DfT from Members of Parliament. Furthermore, there have been discussions within UNECE-GRB (United Nations Economic Commission for Europe - Working Party on Noise)[1] regarding the use of audible warning devices to improve the audibility of these vehicles for the vision-impaired; research into this issue is known to be being actively carried out.

DfT has therefore commissioned TRL to determine the extent of such accidents and whether hybrid/electric vehicles are audibly more difficult to detect than their traditional internal combustion engine powered equivalents and may, therefore, pose more of a safety risk to vision-impaired pedestrians.

The study involves a review of available statistical data and a combination of practical vehicle trials and a subjective audibility trial involving vision-impaired subjects. Based on the outcomes of the study, recommendations will be made as to the need and potential for improving the audibility of quiet vehicles.

For simplicity, the following terminology will be adopted in the remainder of this report; vehicles fitted with traditional internal combustion engines will be referred to as 'ICE'

[1] GRB is a subsidiary body of the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29)

vehicles; vehicles powered by electric motors, either fully electric or hybrid vehicles capable of running in fully electric mode will be referred to as 'E/HE' vehicles.

1.1 Structure of the report

The report is structured as follows:

- Chapter 2 presents a review of statistical data and other research assessing the involvement of pedestrians in accidents with E/HE and ICE vehicles
- Chapter 3 reports on a practical test-track trial of E/HE and ICE vehicles to assess their noise performance under a range of different operating conditions
- Chapter 4 reports on a subjective trial involving vision-impaired participants
- Chapter 5 presents considerations on how the audibility of quiet vehicles should be addressed, based on the findings of Chapters 2-4
- Chapter 6 presents a summary of the work and the overall conclusions from the study
- Appendix A summarises the participant feedback from the subjective trial
- Appendix B provides details of the vehicles and associated manoeuvres used in the audio sequences within the subjective trial
- Appendix C considers the relationship between kerbside noise levels and those at the standard position for vehicle noise measurements, based on steady-speed pass-by noise levels recorded during the practical trials

2 Review of accident statistics involving E/HE vehicles and pedestrians

This chapter presents the findings from a review of the Great Britain national road accident database, STATS19, the On-The-Spot accident investigation project database and research from other countries to assess the involvement of E/HE and ICE vehicles in accidents where there was a collision with a pedestrian.

2.1 Review of GB data – STATS19

Since 1949, police throughout Great Britain have recorded details of road accidents that involve personal injury (be that slight, serious or fatal injury) using a single reporting system which is reviewed and updated regularly. The basic details of the people, vehicles and roads involved in these accidents are recorded, and since 2005 the factors which contributed to accident causation have been included. This database is known as the STATS19 database; further details are available in the DfT publication ‘Reported Road Casualties Great Britain’ (DfT, 2009).

Very few, if any, fatal accidents do not become known to the police. However, research conducted on behalf of DfT in the 1990s (Simpson, 1996) showed that a significant proportion of non-fatal injury accidents are not reported to the police. The most recent work by DfT on levels of reporting and references to earlier reports can be found in articles in two reports (DfT, 2007), (DfT, 2008). Therefore the true absolute accident numbers may be higher than those identified in the following sections, however there is no evidence to suggest that relative comparisons between groups should be affected.

The STATS19 data for pedestrian casualties during the period 2005 to 2008 have been included in this report. More recent data were unavailable at the time of the analysis.

The vehicle registration mark (VRM) has been recorded in STATS19 since 1989. The STATS19 vehicle record is supplemented with information for that vehicle from the Driver Vehicle and Licensing Agency (DVLA) data by DfT. These enhanced vehicle data are provided to TRL by DfT with the STATS19 data and include for example, the make and model, the year of registration and type of propulsion for the vehicle. Information on the makes and models in the enhanced vehicle data is available for about 80% of the cars/vans/taxis involved in accidents with pedestrians, i.e. no VRM was recorded for approximately 20% of the cars/vans/taxis involved in accidents with pedestrians; we do not believe that this is in any way correlated with either the age or type of vehicle.

This report focuses on vehicles (where the make and model could be derived from the STATS19 information) which hit a pedestrian in an accident.

2.1.1 Scope of the analysis

The analysis has been restricted to assessing accident statistics for *vehicles less than 3.5 tonnes Gross Vehicle Weight* (GVW). The basis for this is that there were very few electric vehicles commercially available above 3.5 tonnes GVW for the time period under consideration; only two manufacturers (Modec and Smith Electric Vehicles) were known to produce larger vehicles and fleet sizes would most likely have been small. Furthermore, research from other countries (see Section 2.2) has focussed solely on passenger cars.

The analysis has been performed based on the powertrain type and the vehicle type as follows:

- *Powertrain:* Vehicles have been defined as being either E/HE vehicles (NB. Fully electric and hybrid electric vehicles have been treated as a single powertrain type, regardless of the mode of operation of the hybrid vehicle at the time of the accident) or ICE vehicles
- *Vehicle:* Group 1 comprises cars and car-derived vans due to the complexities of differentiating between the two in STATS19. Group 2 comprises purpose-built vans with a gross vehicle weight (GVW) less than 3.5 tonnes

Analysis of those vehicles involved in accidents has been restricted to those cases where the vehicles involved have physically collided with the pedestrians.

Where multiple vehicles are involved in an accident, only those vehicles which actually collided with a pedestrian are considered.

2.1.2 General accident numbers in the period 2005-2008

Table 2.1 presents the numbers of vehicles involved in general vehicle accidents for the two vehicle groups in the period 2005-2008, i.e. vehicles involved in any kind of accident, not only those involving pedestrian casualties.

Table 2.1: Number of vehicles involved in accidents of any kind, 2005-2008

Vehicle Type	Year	E/HE vehicles	ICE vehicles	All vehicles
Group 1 Passenger cars & car-derived vans	2005	36	205,768	205,804
	2006	63	177,744	177,807
	2007	140	170,440	170,580
	2008	256	183,703	183,959
	2005-2008	**495**	**737,655**	**738,150**
Group 2 Vans < 3.5t GVW	2005	1	12,122	12,123
	2006		11,596	11,596
	2007		10,291	10,291
	2008	1	10,691	10,692
	2005-2008	**2**	**44,700**	**44,702**
Group 1 & Group 2	**2005-2008**	**497**	**782,355**	**782, 852**

It is observed that there were a total of 495 E/HE cars and car-derived vans involved in accidents compared to 737,655 ICE vehicles in the same group. The number of E/HE vehicles involved in accidents is observed to increase year upon year, with approximately 50% of the vehicles involved in accidents occurring in 2008. The number of ICE vehicles involved in accidents declined in the period 2005-2007 but saw an increase in 2008. The reasons for this increase have not been investigated within this study.

Considering vans less than 3.5 tonnes GVW, there were only two E/HE vans involved in accidents in the period of interest compared to 44,700 ICE vans involved in accidents.

2.1.3 Accident numbers involving pedestrian casualties, 2005-2008

Table 2.2 presents the number of vehicles which collided with a pedestrian in an accident for the two vehicle groups in the period 2005-2008.

Table 2.2: Number of vehicles which collided with a pedestrian, 2005-2008

Vehicle Type	Year	E/HE vehicles	ICE vehicles	All vehicles
Group 1 Passenger Cars & car-derived vans	2005	3	17,443	17,446
	2006	9	16,084	16,093
	2007	13	14,080	14,093
	2008	36	15,968	16,004
	2005-2008	**61**	**63,575**	**63,636**
Group 2 Vans < 3.5t GVW	2005		1,110	1,110
	2006		1,010	1,010
	2007		982	982
	2008	1	933	934
	2005-2008	**1**	**4,035**	**4,036**
Group 1 & Group 2	**2005-2008**	**62**	**67,610**	**67,672**

It is observed that there were a total of 61 E/HE cars/car-derived vans that collided with a pedestrian in accidents between 2005 and 2008, compared to 63,575 ICE cars/car-derived vans. As with the general accidents involving these E/HE vehicles, the number of E/HE vehicles involved in accidents increased year on year, with over 50% of the vehicles being involved in accidents occurring in 2008. For the ICE vehicles, the same trend is observed as for general accidents involving ICE vehicles.

Considering vans less than 3.5 tonnes GVW, there was only a single accident involving a collision between an E/HE van and a pedestrian in the period of interest compared to 4,035 ICE vans colliding with a pedestrian.

One of the parameters recorded within STATS19 is the contributory factor (CF) 810, 'Disability or illness, mental or physical' which may be assigned to a pedestrian if, in the opinion of the reporting officer, a disability or illness, be it either mental or physical, contributed to the accident. This contributory factor includes when the pedestrian is either suddenly overcome by illness, e.g. blackout, is generally affected by illness, e.g. a cold or influenza, or is suffering from a permanent disability (including poor eyesight) which contributed to the accident (DfT, 2004). An assessment of the 62 accidents in Table 2.2 identified that only 2 of the pedestrians hit by a vehicle were assigned CF810.

2.1.4 Number of registered vehicles

In order to make a robust interpretation of the data displayed above it is necessary to make the data comparable. A common method is to compare accident data relative to the number of miles travelled by the particular group of vehicles of interest. In this case, where the driving habits of E/HE drivers is in general likely to be different to ICE drivers (e.g. mileage is likely to be less and driving more likely to be in urban areas due to range limitations for E/HE vehicles), a basis to make the data comparable might be the number of accidents occurring in urban areas relative to the number of miles travelled in urban areas. However these data are not available and therefore the number of registered vehicles by powertrain is the next best source of exposure data available.

DfT have supplied the numbers of vehicles in the two categories currently registered on the last day of each year by make and model.

These data have been used to obtain the numbers of E/HE and ICE cars, car-derived vans and vans less than 3.5 tonnes GVW registered for the years 2005-2008. Table 2.3 shows these figures as well as the percentage of each part of the vehicle fleet comprised of E/HE vehicles.

Table 2.3: Number of registered vehicles by type, 2005-2008

Vehicle Type	Year	E/HE vehicles	ICE vehicles	All vehicles	% of fleet comprising E/HE vehicles
Group 1 Passenger cars & car-derived Vans	2005	8,629	27,511,769	27,520,398	0.03
	2006	17,456	27,591,715	27,609,171	0.06
	2007	32,966	27,967,298	28,000,264	0.12
	2008	48,071	28,112,631	28,160,702	0.17
	2005-2008	107,122	111,183,413	111,290,535	0.10
Group 2 Vans < 3.5t GVW	2005	5,145	2,938,231	2,943,376	0.17
	2006	4,769	3,018,306	3,023,075	0.16
	2007	4,376	3,144,509	3,148,885	0.14
	2008	4,183	3,187,220	3,191,403	0.13
	2005-2008	18,473	12,288,266	12,306,739	0.15
Group 1 & Group 2	2005-2008	125,595	123,471,679	123,597,274	0.10

2.1.5 Analysis of accident involvement rates

For each vehicle category and powertrain type, the *vehicle involvement density* per 10,000 registered vehicles is defined as the number of vehicles involved in accidents relative to the number of registered vehicles and given by

$$\text{Vehicle involvement density} = \sum_{Y=1}^{N} NVIA_Y \Bigg/ \sum_{Y=1}^{N} NR_Y$$

where *Y* denotes the year of interest, *N* is the number of years of interest, $NVIA_Y$ is the number of E/HE (or ICE) vehicles involved in accidents in year *Y*, and NR_Y is the number of registered E/HE (or ICE) vehicles in the year *Y*.

Pedestrian vehicle involvement density, per 10,000 registered vehicles, addresses those vehicles which are involved in a collision with the pedestrian and can be calculated in a similar manner. As noted previously, where multiple vehicles are involved in an accident, only those vehicles which actually collided with a pedestrian are considered.

Table 2.4 compares the vehicle involvement densities for E/HE and ICE vehicles during the period 2005-2008.

The relative rate, also presented in the table, is calculated by dividing the vehicle involvement density for E/HE vehicles by the vehicle involvement density for ICE vehicles. This relative rate is used to compare the two vehicle involvement densities; if the vehicle involvement density for E/HE vehicles is higher than that for ICE vehicles then the relative rate will be greater than one and vice versa.

Table 2.4: Vehicle involvement densities per 10,000 registered vehicles, 2005-2008

Vehicle Type	Year	E/HE vehicles	ICE vehicles	All vehicles	Relative accident rate for E/HE vehicles
Group 1 Passenger cars & car-derived vans	2005	41.7	74.8	74.8	0.56
	2006	36.1	64.4	64.4	0.56
	2007	42.5	60.9	60.9	0.70
	2008	53.3	65.3	65.3	0.81
	2005-2008	**46.2**	**66.3**	**66.3**	**0.70**
Group 2 Vans < 3.5t GVW	2005	---*	41.3	41.2	---*
	2006	---*	38.4	38.4	---*
	2007	---*	32.7	32.7	---*
	2008	---*	33.5	33.5	---*
	2005-2008	**---***	**36.4**	**36.3**	**---***
Group 1 & Group 2	**2005-2008**	**39.6**	**63.4**	**63.3**	**0.62**

* Numbers are too small to produce robust estimates

The following is observed:

- The results in Table 2.4 show that the relative rate for the combination of E/HE cars and car-derived vans increases from 0.56 to 0.81 over the time period of interest, suggesting that the vehicle involvement density for the E/HE vehicles was lower but becoming more comparable to that for ICE vehicles

- Over the four year period, then *relative to the number of registered vehicles*, E/HE cars and car-derived vans were 30% less likely to be involved in an accident than ICE vehicles. It is seen from Table 2.1 that the absolute number of E/HE vehicles involved in accidents is considerably less than the number of ICE vehicles involved in accidents (495 vehicles compared to 737,655)
- Vehicle involvement densities for E/HE vans less than 3.5 tonnes GVW are not calculated due to the low actual number of accidents (only 2 over the four year period). The number of ICE vehicles involved in accidents was 44,700 (from Table 2.1)
- Considering the combination of both vehicle groups, then the results suggest that *relative to the number of registered vehicles*, E/HE vehicles were 38% less likely to be involved in an accident than ICE vehicles. Again, the absolute number of E/HE vehicles involved in accidents is considerably less than the number of ICE vehicle involved in accidents (497 vehicles compared to 782,355, from Table 2.1)

It must be noted that these rates take no account of either the vehicle speed or the location of the accident (the latter in terms of whether it occurred in a built-up or not-built up area). This is discussed later in this section.

Table 2.5 compares the pedestrian vehicle involvement densities for E/HE and ICE vehicles during the period 2005-2008.

The relative rate, also presented in the table, is calculated by dividing the pedestrian vehicle involvement density for E/HE vehicles by the pedestrian vehicle involvement density for ICE vehicles. This relative rate is used to compare the two pedestrian vehicle involvement densities in a similar manner to the comparison of vehicle involvement densities.

The following is observed:

- The rates presented in Table 2.5 show that the relative rate when pedestrian casualties occur has increased for E/HE vehicles from 0.55 to 1.32 over the time period of interest, meaning that the pedestrian vehicle involvement density for E/HE vehicles has risen from being relatively lower than that for ICE vehicles to higher than that for ICE vehicles in 2008. There is insufficient data to confirm that whether this higher rate has continued beyond 2008
- Considering the full four year period, then *relative to the number of registered vehicles,* E/HE cars and car-derived vans were equally as likely to be involved in a collision with a pedestrian as ICE vehicles. Again, it is seen from Table 2.2 that the absolute number of E/HE vehicles colliding with pedestrians is considerably less than the number of ICE vehicles (61 vehicles compared to 63,575)

Table 2.5: Pedestrian vehicle involvement densities per 10,000 registered vehicles, 2005-2008

Vehicle Type	Year	E/HE vehicles	ICE vehicles	All vehicles	Relative accident rate for E/HE vehicles
Group 1 Passenger cars & car-derived vans	2005	3.5	6.3	6.3	0.55
	2006	5.2	5.8	5.8	0.88
	2007	3.9	5.0	5.0	0.78
	2008	7.5	5.7	5.7	1.32
	2005-2008	**5.7**	**5.7**	**5.7**	**1.00**
Group 2 Vans < 3.5t GVW	2005	---*	3.8	3.8	---*
	2006	---*	3.3	3.3	---*
	2007	---*	3.1	3.1	---*
	2008	---*	2.9	2.9	---*
	2005-2008	**---***	**3.3**	**3.3**	**---***
Group 1 & Group 2	**2005-2008**	**4.9**	**5.5**	**5.5**	**0.90**

* Numbers are too small to produce robust estimates

- Pedestrian vehicle involvement densities for E/HE vans less than 3.5 tonnes GVW are not calculated due to the low actual number of accidents (only 1 over the four year period). The number of ICE vehicles involved in collisions with pedestrians was 4,035 (from Table 2.2)
- Considering the combination of both vehicle groups, then the results suggest that *relative to the number of registered vehicles*, E/HE vehicles were 10% less likely to be involved in a collision with a pedestrian than ICE vehicles. Again, the absolute number of E/HE vehicles involved is considerably less than the number of ICE vehicle (62 vehicles compared to 67,610, from Table 2.2).

Again, it must be noted that these rates take no account of the vehicle speed or the location of the accident (which is more likely to be comparable between the two powertrain types for this type of accident). This is discussed later in this section.

In conclusion, where the individual relative rates are less than or equal to 1.0, the results suggest that there is no direct statistical accident evidence to support the perceived increase in risk to pedestrians from E/HE vehicles. There were only two E/HE accidents involving a collision with a pedestrian who was disabled in some way (CF810) so it is not possible to make a judgement on the perceived risk to vision-impaired pedestrians.

Comparing the relative rate for E/HE vehicles involved in all accidents (0.62) with the relative rate of E/HE vehicles which collide with a pedestrian (0.90) suggests that although the relative number of E/HE vehicles involved in accidents is smaller, proportionately more of these vehicles hit a pedestrian than ICE vehicles. Considering the combination of passenger cars and car-derived vans only, the relative rates are 0.70 and 1.0.

Whilst this potentially supports the perceived increase in pedestrian risk for E/HE vehicles, the limitations of the statistical assessment must be recognised and may provide an alternative explanation for the results:

- The accident rates for E/HE vehicles may reflect their usage patterns. The location of the accident and the nature/speed of the vehicle manoeuvre at the time of the accident have not been taken into account in the analysis.

  As a consequence of the limited range, the rates take no account of the fact that the annual mileage driven by ICE vehicles may be considerably greater than that for fully electric vehicles, hence the lower accident rate. The use of HE vehicles is likely to be more comparable to that of ICE vehicles. The limited range for fully electric vehicles means that they are more likely to be used in urban areas, hence the similar pedestrian accident rate to ICEs.

- Fully electric and hybrid electric vehicles have not been treated as separate datasets. In the case of hybrid electric vehicles, it is not possible to determine whether or not the vehicle was running in full electric mode at the time of the accident. Even the use of speed limit data recorded within STATS19 will not robustly confirm this.

Determination of the involvement densities based on narrower vehicle categories and exposure data appropriate to urban areas would therefore provide a more robust assessment of the relative risk posed by electric vehicles. However whilst the former can be achieved, the availability of suitable urban exposure data is considered unlikely.

The reported accident data used to derive the pedestrian vehicle involvement densities do not record whether a lack of noise from the vehicle was a contributory factor where the vehicle collided with a pedestrian. As such, the relative rates for pedestrian vehicle involvement density cannot be used as the sole evidence for any need to improve the detectability of E/HE vehicles through the addition of 'added sound' to E/HE vehicles. Further support is needed from practical measurements of vehicle noise and audio assessments by vision-impaired individuals. These activities have also been undertaken as part of the current study and are reported in Chapters 3 and 4 respectively.

2.1.6 Assessment of the effects of general accident location and injury severity

Table 2.6 presents the injury severity for accidents involving passenger cars/car-derived vans which collided with a pedestrian in terms of the speed limit at the site of the accident.

Whilst built-up areas are commonly defined as being those where the speed limit is 40 mph or less, the possible risk to vision-impaired pedestrians from electric vehicles is more likely to be an issue during low-speed operation when engine noise replaces tyre/road noise as the dominant noise source from road vehicles. The table therefore presents results based around a speed limit of 30 mph (whilst the use of 20 mph zones is increasing, 30 mph is still the more common speed limit in areas where there are high levels of pedestrian activity).

As might be expected, the majority of accidents where the vehicle collided with a pedestrian occur in areas with speed limits of 30 mph or less, regardless of vehicle powertrain type (93.4% for E/HE vehicles and 91.4% for ICE vehicles).

Table 2.6: Assessment of injury severity and general accident location for passenger cars and car derived vans involved in collisions with pedestrians

Speed limit	Year	KSI (Killed or serious injury)		Slight injury		All injury severities	
		E/HE vehicles	ICE vehicles	E/HE vehicles	ICE vehicles	E/HE vehicles	ICE vehicles
Speed limit 30 mph or less	2005	1	3,342	2	12547	3	15889
	2006	3	3,283	6	11346	9	14629
	2007	2	2,893	11	9981	13	12874
	2008	11	3,387	21	11315	32	14702
	2005-2008	17	12,905	40	45189	57	58094
	% of total vehicles	94.4%	85.7%	93.0%	93.2%	93.4%	91.4%
Speed limit 40, 50, 60 or 70 mph	2005		582		972		1554
	2006		577		878		1455
	2007		480		726		1206
	2008	1	520	3	746	4	1266
	2005-2008	1	2159	3	3322	4	5481
	% of total vehicles	5.6%	14.3%	7.0%	6.8%	6.6%	8.6%
Total accidents		18	15064	43	48511	61	63575

It is noted that the speed data reported in STATS19 is the speed limit of the road on which the accident occurred and not the speed of the vehicle at the time of the accident. It is therefore not possible to determine the actual speed of the vehicle and thereby whether hybrid electric vehicles were operating in full electric mode. Furthermore, it cannot therefore be determined whether reduced noise from E/HE vehicles was a contributory factor in the accident.

A further breakdown of accidents by parameters such as location (at or away from junctions and the availability of pedestrian crossing facilities) and vehicle manoeuvre was considered. However, the E/HE dataset was too small to allow a meaningful comparison to be drawn.

Summary of findings from the accident statistics

Relative to the number of registered vehicles, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were 30% less likely to be involved in an accident than ICE vehicles (495 accidents compared to 737,655). Introducing vans < 3.5 tonnes GVW into the vehicle group, then E/HE vehicles were 38% less likely to be involved in an accident than ICE vehicles (497 accidents compared to 782,355).

Summary of findings from the accident statistics (Continued...)

Relative to the number of registered vehicles, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were equally as likely to be involved in a collision with a pedestrian as ICE vehicles (61 accidents compared to 63,575). Introducing vans < 3.5 tonnes GVW into the vehicle group, then E/HE vehicles were 10% less likely to be involved in a collision with a pedestrian than ICE vehicles (62 compared to 67,610).

While the relative rates are all less than one, comparing the relative rate for E/HE vehicles involved in all accidents (0.62) with the relative rate of E/HE vehicles which collided with a pedestrian (0.90) suggests that although the relative number of E/HE vehicles involved in accidents is smaller, proportionately more of these vehicles hit a pedestrian than ICE vehicles. Considering the combination of passenger cars and car-derived vans only, the relative rates are 0.70 and 1.0. Whilst this potentially supports the perceived increase in pedestrian risk for E/HE vehicles, it may be that the accident rates reflect the usage patterns of E/HE vehicles; total mileages for E/HE vehicles may be lower than ICEs hence the lower overall accident rate, but a higher proportion of their use may be in urban areas, hence the similar pedestrian accident rate to ICEs.

There were only two E/HE accidents involving a collision with a pedestrian who was disabled in some way (CF810) so it is not possible to make a judgement on the perceived risk to vision-impaired pedestrians.

However, none of the relative rates take account of vehicle speed, vehicle manoeuvre or the location of the accident, e.g. whether or not the accident occurred in a built-up area. Additionally, no differentiation is made between fully electric and hybrid electric vehicles.

Considering only passenger cars and car-derived vans, the majority of accidents in which vehicles collided with pedestrians occurred where speed limits are 30 mph or less regardless of vehicle powertrain type (93.4% for E/HE vehicles and 91.4% for ICE vehicles). It was not possible to determine the speed of the vehicles at the time of the accident and as such it is unknown whether hybrid vehicles were operating in full electric mode at the time of the accident. Furthermore, it cannot therefore be determined whether reduced noise from E/HE vehicles was a contributory factor in the accident.

The E/HE vehicle dataset was too small to allow a more detailed, meaningful assessment of the accident statistics in terms of parameters such as location (at or away from junctions and the availability of pedestrian crossing facilities) and vehicle manoeuvre.

2.2 Review of other data sources

The On The Spot (OTS) accident investigation project involves sending a team of researchers to the scenes of road traffic accidents in the same timeframe as the emergency services, with an aim of creating a greater understanding of the causes and consequences of road traffic accidents. An interrogation of the latest OTS release which includes all TRL and VSRC (Vehicle Safety Research Centre) cases investigated to date yielded no accidents relevant to this study.

A report by the US National Highway Traffic Safety Administration (NHTSA) has investigated incidences involving collisions between hybrid passenger cars and pedestrians or cyclists (NHTSA, 2009) based upon data collected from State Data Systems (SDSs), which include details of all police-reported crashes, regardless of injury or crash outcome. It is noted that the SDS does not include information on the vision status of the pedestrians involved in incidents and as such the study did not address this factor.

Data covering the period 2000-2007 were analysed in the study, based on data from only 12 out of 50 States (those States where the SDS included vehicle identification numbers). However, it is noted that the data from the different States were not uniform in terms of content or the years for which data were available. Comparisons were drawn between incidents involving hybrid and ICE vehicles.

Although the report analyses the conditions under which all accidents occurred as well as those accidents only involving pedestrian casualties, the following sections will present the latter results to allow the most robust comparison with the UK findings.

Pedestrian accident involvement rates

Table 2.7 compares the accident figures from the US study for the different vehicle types and determines the percentage of accidents involving pedestrian casualties. For comparative purposes, the equivalent GB data from the STATS19 are also included (noting that this is the combination of passenger cars and car-derived vans).

Table 2.7: Pedestrian accident involvement rates

Scenario under consideration	US data (NHTSA)		GB data (STATS19)	
	Hybrid vehicles only	ICE Vehicles	Electric and hybrid vehicles	ICE Vehicles
Total No. of cars involved in accidents	8,387	559,703	495	737,655
Number of cars resulting a pedestrian casualty	77	3,578	61	63,575
% of cars involved in accidents resulting in a pedestrian casualty	0.9%	0.6%	12.3%	8.6%

It is noted that the total number of registered vehicles in the relevant US states corresponding to the study period was not available. This prevented any assessment of relative accident rates in the manner presented in Table 2.5.

The table shows that the while the accident rates for accidents involving a pedestrian casualty are significantly lower in the US than in Great Britain regardless of vehicle category, the ratio of the percentage of non-ICE vehicles to ICE vehicles involved in accidents involving a pedestrian casualty is similar for both countries (approximately 1.5). However this may be influenced by several factors:

- The total number of accidents involving E/HE vehicles was significantly higher in the US. This is likely to have been because there were a far greater number of hybrid vehicles in use in the US at that time than in Great Britain
- While the total number of accidents for non-ICE vehicles involving pedestrian casualties is of a similar order of magnitude to that in the Great Britain, it must be noted that the US study considered only hybrid vehicles whilst the GB data is based on a combination of fully electric and hybrid vehicles
- There are significantly fewer accidents involving ICE cars and pedestrian casualties in the US. This may be due to factors related to pedestrian behaviour in relation to crossing roads. In the US, there is likely to be less pedestrian activity outside of urban areas due to distances between cities, towns and amenities being greater than in the UK. Furthermore, in the US, state statutes generally reflect the Uniform Vehicle Code (traffic laws prepared by the National Committee on Uniform Traffic Laws and Ordinances) in requiring drivers to yield the right of way to pedestrians at crossings. At other locations, crossing pedestrians are either required to yield to drivers or, under some conditions, are prohibited from crossing. There are no such formally prescribed regulations for drivers and pedestrians in the UK, except with regard to marked Zebra, Pelican, and Puffin crossings, where motorists are required to give way to pedestrians under defined conditions.

Based on the data available, less than 1% of either hybrid or ICE vehicle accidents reported in selected US states involve pedestrian casualties compared to 12% in Great Britain. It is noted that the number of US states included in the analysis is only about 25% of the total number of states and that the reporting periods were not consistent between the states.

3 Test track assessments of quiet and not-quiet vehicles

A programme of practical measurements has been undertaken to determine the noise levels generated by E/HE vehicles in comparison to ICE vehicles, and the associated noise characteristics.

It is observed that whilst a range of fully-electric passenger cars are being gradually introduced onto the market, many of these are still undergoing limited public trials and as such their availability is still quite restricted. Four E/HE vehicles were selected for inclusion in the study, influenced by this availability.

Four ICE vehicles were selected for inclusion in the test programme that were of similar size and type to the E/HE vehicles.

3.1 Overview of the tests conducted within the test programme

While accidents involving E/HE vehicles and pedestrians are most likely to occur in urban areas, the overall objective of the study is to determine whether electric vehicles are more difficult to detect than their ICE counterparts. Since background noise levels and characteristics vary from location to location, the most robust approach was to measure and compare noise levels with as little background noise as possible. In order to try and achieve this, the practical measurements were conducted on TRL's dedicated vehicle test track. Such an approach addresses the best case scenario for assessing vehicle noise and detectability. As background noise levels increase so it is likely that, particularly at low speeds, distinguishing between the vehicle types will become more difficult.

The test programme can be summarised as follows:

- *Steady-speed pass-by tests:* Target speeds of 5[2], 20, 30 and 50 km/h were selected.
- *Pull-away from rest tests:* Target acceleration rates of 0.5ms^{-2} and 1.0ms^{-2} were selected.
- *Low-speed parking tests:* No specific target speeds were defined. Vehicles were both driven forwards and reversed out of a conventional parking space at typical speeds.
- At least 3 measurements were taken for each test condition. 'Kerbside' noise levels and binaural audio recordings of the resulting vehicle noise were taken for all scenarios. The binaural recording headphones were placed on an artificial head mounted on a tripod at a height of 1.65m, to represent a typical pedestrian standing at the kerbside, as shown in Figure 3.1.

Figure 3.1: Set-up for binaural audio recording

[2] It is noted that whilst 5 km/h was set as the slowest target speed, this could not generally be achieved by the majority of vehicles; 7-8 km/h was the typical slowest constant speed achievable.

- The operation of the noise monitoring equipment was controlled by light gates at each end of the test site, the first gate starting the measurement, the second gate ending the measurement.

Coast-by measurements were originally proposed but these were generally prevented by vehicles having automatic gearboxes or electronic (keyless) ignition systems. A matrix showing which tests were conducted for each vehicle is presented in Table 3.1.

Further details of the individual tests are presented in the following sections. Where measurements were not carried out, this was a result of the measurements being disrupted by bad weather. In the case of vehicle ICE-02, one of the parking measurements was not undertaken because the vehicle could not be driven out of the parking space in a single manoeuvre.

Table 3.1: Vehicle measurement scenario index

Vehicle type, manufacturer and model		Steady-speed drive-by				Pull-away from rest (acceleration)		Parking manoeuvres	
		7-8 km/h	20 km/h	30 km/h	50 km/h	0.5 ms^{-2}	1.0 ms^{-2}	Reverse out of space	Forwards out of space
Internal combustion engine vehicles	ICE-01	✓	✓	✓	✓	✓	✓	✓	✓
	ICE-02	✓	✓	✓	✓	✓	✓	---	✓
	ICE-03	✓	✓	✓	✓	✓	✓	✓	✓
	ICE-04	✓	✓	✓	✓	---	---	✓	✓
Hybrid & electric vehicles	E/HE-01	✓	✓	✓	✓	✓	✓	✓	✓
	E/HE-02	✓	✓	✓	✓	✓	✓	✓	✓
	E/HE-03	✓	✓	✓	✓	✓	✓	---	---
	E/HE-04	✓	✓	✓	✓	✓	✓	✓	✓

3.1.1 Steady-speed pass-by tests

Steady-speed pass-by measurements were conducted for each vehicle using the test arrangement shown in Figure 3.2 on the TRL test track.

The road surface was a 14mm Stone Mastic Asphalt (SMA)[3] and the ground to the left of the running lane was concrete. Microphones were placed in a straight line perpendicular to the running lane at distances of 1.8m (equivalent to the position of a pedestrian at the kerbside), and 7.5m from the centre of the running lane. These corresponded to the nearside kerb and the standard position for traffic noise measurements as defined in ISO 11819-1:2001 (ISO, 2001).

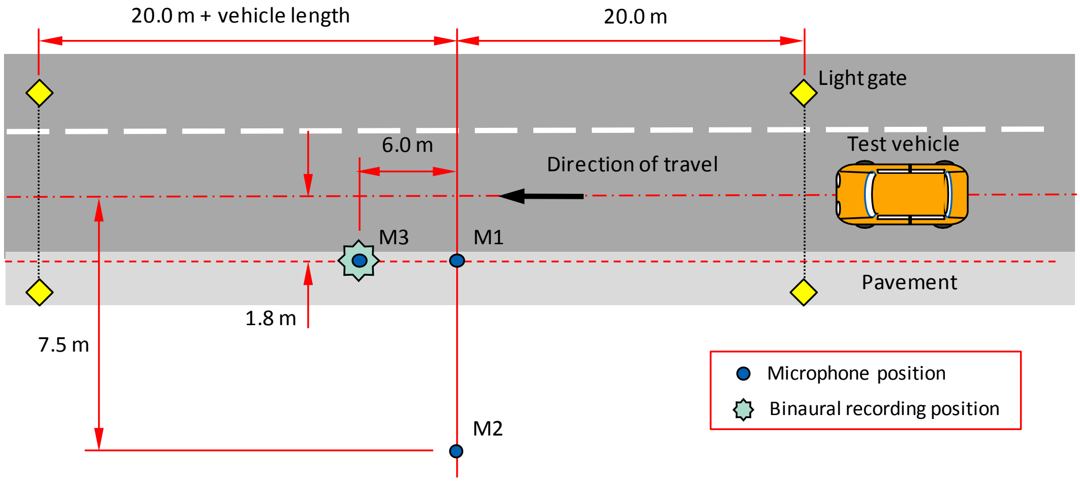

Figure 3.2: Test arrangement for steady speed pass-by tests

Binaural headphones and an additional microphone (M3) were placed at the kerbside position, 6m beyond the main pass-by microphone positions, i.e. at 26m beyond the light gate.

The test vehicle was driven so that it was at the desired steady speed (7-8, 20, 30 or 50 km/h) at least 10m before the vehicle passed through the first light gate, and that speed was maintained until after the vehicle passed through the second light gate.

3.1.2 *Pull-away from rest tests*

The pull-away from rest (acceleration) measurements were conducted using the test arrangement shown in Figure 3.3 at the same location on the TRL test track.

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[3] Stone Mastic Asphalt is a commonly used low-noise road surface. Whilst the primary application of the surface is on England's strategic road network (which includes most motorways and some major "A" classified roads), it is being increasingly used in urban areas, e.g. as proposed in the Mayor of London's noise strategy which states that "*Transport for London will, and London boroughs and others should, use noise-reducing surfaces, where practicable and cost-effective, and where they do not compromise safety, particularly skidding resistance, and other criteria*" (Mayor of London, 2004).

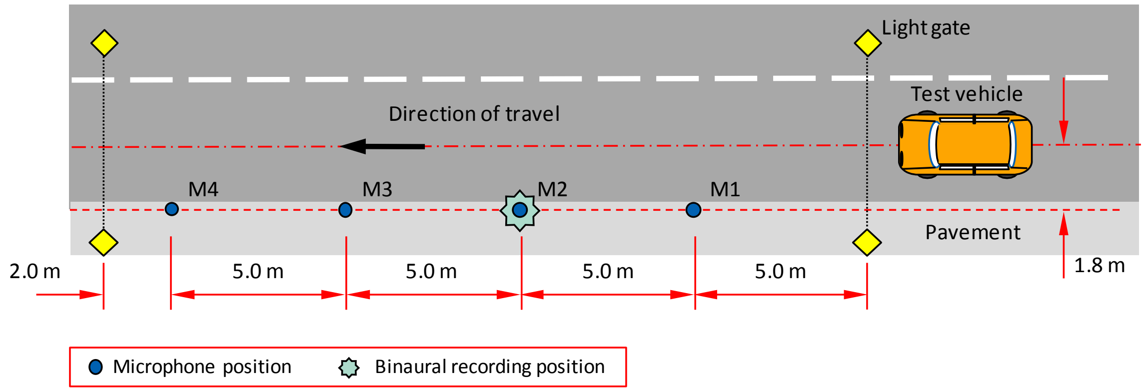


Figure 3.3: Test arrangement for pull-away-from rest tests

Four microphones were placed at 5m intervals at 1.8m from the centre of the running lane. This configuration was devised to capture how the noise of the vehicle changed as it accelerated. The binaural headphones were placed at the second microphone position.

The test vehicle commenced each measurement from a stationary position immediately before the first light gate, accelerating at a steady rate of either 0.5 or 1.0ms^{-2} until it passed through the second light gate.

3.1.3 Low-speed parking manoeuvre tests

The set-up for the low speed parking measurements is depicted in Figure 3.4. This was conducted on a flat asphalt surface, where the dimensions of the parking spaces and walkways were based on those found in typical car parks.

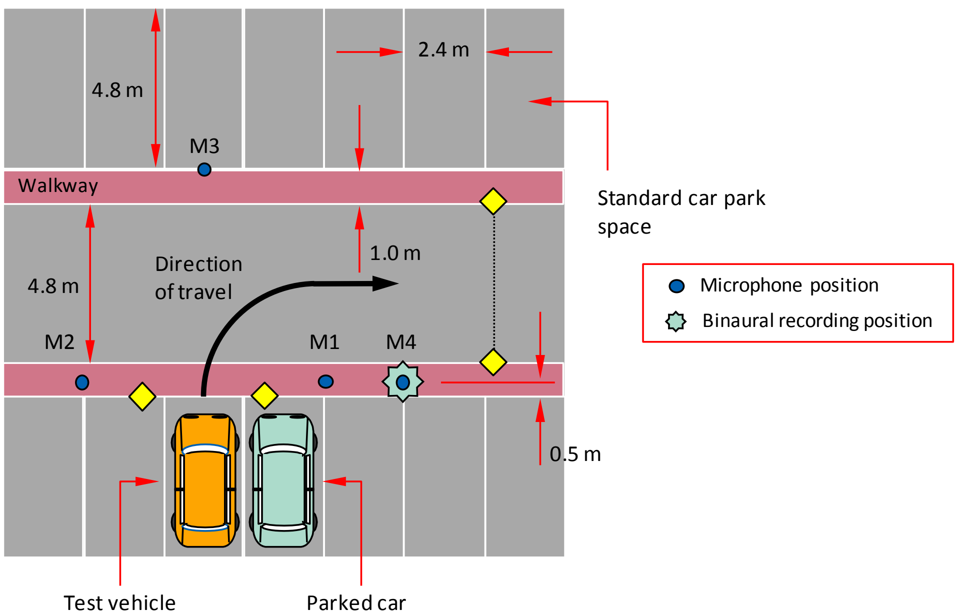


Figure 3.4: Test arrangement for low-speed parking manoeuvres

A parked car was positioned next to the space that the test vehicle would be manoeuvring from to represent a likely setup in a typical car park. Microphones were placed one car park space away from the test vehicle in both directions and a third was placed opposite the space, representing the "other side" of that row of the car park. Binaural headphones and a fourth microphone were placed two spaces away from the test vehicle's space.

Measurements were taken with the vehicle either driving forwards or reversing out of the space, travelling in front of the parked car. The first light gate was placed at the edge of the parking space, so that measurements would commence as soon as the vehicle began to move.

The manoeuvre was performed in a single attempt at low speed until the vehicle passed through the second light gate clear of microphone M4.

3.2 Results and analysis

3.2.1 Assessment of overall noise levels under steady-speed pass-by conditions

The maximum noise levels recorded at microphone M3 during the steady-speed pass-by tests are presented in Table 3.2.

Table 3.2: Maximum pass-by noise levels at microphone position M3

Vehicle	Maximum noise level, dB(A)			
	7-8 km/h	20 km/h	30 km/h	50 km/h
ICE-01	57	62	69	77
ICE-02 (not included in the analysis below)	65	74	75	81
ICE-03	51	62	68	77
ICE-04	58	66	73	81
E/HE-01	56	64	70	79
E/HE-02	53	63	70	77
E/HE-03	52	63	70	76
E/HE-04	56	66	72	80
Noise level range (all vehicles*)	**7**	**4**	**5**	**5**
Noise level range (ICE vehicles only*)	**7**	**4**	**5**	**4**
Noise level range (E/HE vehicles only)	**4**	**3**	**2**	**4**

*Vehicle ICE-02 is excluded in the derivation of these ranges because noise levels generated by the vehicle, a van, at speeds of up to 20 km/h were significantly greater than those from other vehicles and as such the vehicle is considered to be an outlier

It should be noted that all of these noise levels were recorded under *semi-rural background noise conditions*, i.e. background noise levels that were generally low enough not to interfere with measurements. The background noise during the 7-8 km/h pass-bys was typically 3 dB(A) below the measured vehicle noise levels. This illustrates that the selection of the test site is very important with regard to any tests involving quiet vehicles. Whilst conventional type approval tests require the measured noise levels to be 10 dB(A) above the background noise level, the current study required a background level that was devoid of other traffic but included other typical semi-rural/rural noise.

The noise levels presented in the Table suggest that the noise levels from vehicle ICE-02, a van, were significantly greater at speeds up to 20 km/h than those from the other vehicles. The vehicle has therefore been classed as an outlier within the dataset and excluded from the following analysis.

Consider first, the maximum recorded noise levels for the 7-8 km/h pass-by. The E/HE vehicles were from 2 dB(A) quieter to 1 dB(A) louder than the ICE vehicles. On average, the E/HE vehicles were only 1 dB(A) quieter than the ICE vehicles. To put this into context, a 3 dB(A) increase in noise level will be detectable by an adult with normal hearing.

It is observed that of the four ICE vehicles, there is a considerable spread in levels. The quietest ICE vehicle is comparable to the quietest of the E/HE vehicles. For the E/HE vehicles, the spread is less than that for the ICE vehicles.

Therefore any move to increase the audibility of E/HE vehicles at low speeds may also potentially have to take into account not only all future model ‘quiet’ ICE vehicles, but potentially recent/current models already within the current vehicle fleet. It may therefore be necessary to develop a limit value below which a vehicle (either E/HE or ICE) is considered to be quiet. The current sample group is, however, too small to allow such a value to be estimated. To verify existing models already on the vehicle fleet as quiet may not be possible unless limit values can be derived from existing noise data, e.g. that already recorded during type approval testing. As such, it is unlikely that these vehicles would be considered.

At higher speeds, the comparison between the E/HE and ICE vehicles was as follows:

- At a speed of 20 km/h, the E/HE vehicles were either comparable to or up to 1 dB(A) louder than the ICE vehicles (1 dB(A) louder on average)
- At a speed of 30 km/h, the E/HE vehicles were from 1 dB(A) quieter to 2 dB(A) louder than the ICE vehicles (0.5 dB(A) louder on average)
- At a speed of 50 km/h, the E/HE vehicles were 1 dB(A) quieter than the ICE vehicles (comparable on average)

At these speeds, the range across all vehicles, and between vehicle categories, is more consistent as may be expected as tyre/road noise becomes the dominant source. The spread at higher speeds is affected by tyre size; larger tyres will have a larger contact patch and therefore are more likely to be noisy. At these higher speeds the E/HE vehicles are not noticeably quieter than their ICE counterparts.

The maximum noise levels presented in Table 3.2 are plotted in Figure 3.5 where it can be seen that all vehicles exhibit a similar trend with respect to increasing noise level as speed increases. The exceptions to this being ICE-01 and EH/E-01 which exhibit relatively linear increases in noise with speed; there are no clear reasons for this.

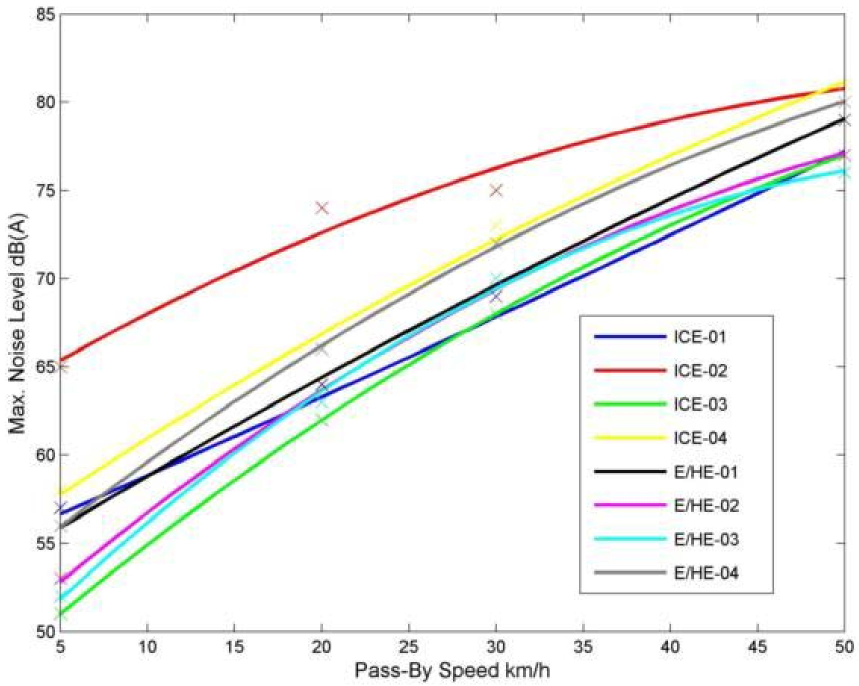


Figure 3.5: Maximum noise levels for steady-speed pass-by measurements

3.2.2 Assessment of overall noise levels under pull-away from rest conditions

The maximum noise levels recorded at microphone positions M1-M4 during the pull-away from rest tests are presented in Table 3.3.

Excluding vehicle ICE-02 from the analysis (as described previously), then these data show that in terms of overall maximum levels, then the noise levels from E/HE vehicles at the lower acceleration rate were either comparable to or 1 dB(A) quieter than the ICE vehicles (1 dB(A) quieter on average); at the higher acceleration rate, the E/HE vehicles were from 2 dB(A) quieter to 3 dB(A) noisier than the ICE vehicles (comparable on average).

Considering the levels at the different microphones, the results show that E/HE vehicles can, over the initial period of acceleration, be marginally quieter than their ICE counterparts but after the first 5m both vehicle types have broadly similar noise levels.

3.2.3 Assessment of overall noise levels during parking manoeuvres

Due to the nature of the manoeuvres, the speeds for the vehicles pulling out of the parking spaces were of the order of the slowest pass-by speeds, i.e. 7-8 km/h. An assessment of the measurement results identified that the absolute noise levels for the majority of the vehicles were not significantly above the background noise levels at the test location. As such, a table of maximum levels associated with parking measurements would be misleading. However the audio recordings of the measurements have been used as part of the subjective audio trials reported in Chapter 4.

Table 3.3: Maximum noise levels from pull-away from rest tests

Vehicle	Acceleration test at $0.5ms^{-2}$					Acceleration test at $1.0ms^{-2}$				
	Overall maximum	M1	M2	M3	M4	Overall maximum	M1	M2	M3	M4
ICE-01	63	61	62	62	63	69	65	66	67	69
ICE-02 (not included in the analysis below)	81	76	79	80	81	79	74	76	78	79
ICE-03	64	62	63	63	64	68	64	66	67	68
ICE-04	----	---	---	---	---	---	---	---	---	---
E/HE-01	64	60	62	64	64	72	67	69	70	72
E/HE-02	62	58	61	62	62	68	64	65	67	68
E/HE-03	62	57	60	61	62	66	60	63	65	66
E/HE-04	63	58	60	62	63	69	64	67	68	69
Noise level range (all vehicles*)	**2**	---	---	---	---	**6**	---	---	---	---
Noise level range (ICE only*)	**1**	---	---	---	---	**1**	---	---	---	---
Noise level range (E/HE)	**2**	---	---	---	---	**6**	---	---	---	---

*Vehicle ICE-02 is excluded in the derivation of these ranges because noise levels generated by the vehicle, a van, at speeds of up to 20 km/h were significantly greater than those from other vehicles and as such the vehicle is considered to be an outlier

3.2.4 Comparison of the noise characteristics of E/HE and ICE vehicles

The noise characteristics of the different vehicle types have been assessed using one-third octave band noise levels to determine whether the different powertrain options on similar vehicle types have specific frequency characteristics that can clearly enable pedestrians to distinguish between them.

Figure 3.6 shows the one-third octave spectra corresponding to the maximum level recorded during a steady-speed pass-by at 20 km/h.

Peaks in the spectra below 100 Hz, relating to exhaust noise, are observed for the ICE vehicles. These peaks aside, the figure shows that there is no significant difference between the spectral content of ICE and E/HE vehicles, and as such nothing that suggests a pedestrian would clearly be able to differentiate between vehicle types. This may in part be a result of tyre/road noise becoming more dominant at this speed.

A review of the corresponding data at 7-8 km/h has indicated that spectral profiles of the different vehicle types exhibit no distinguishing characteristics which differentiate between them. This is in part a result of the fact that the noise levels of the vehicles at this speed are quite close to the background level.

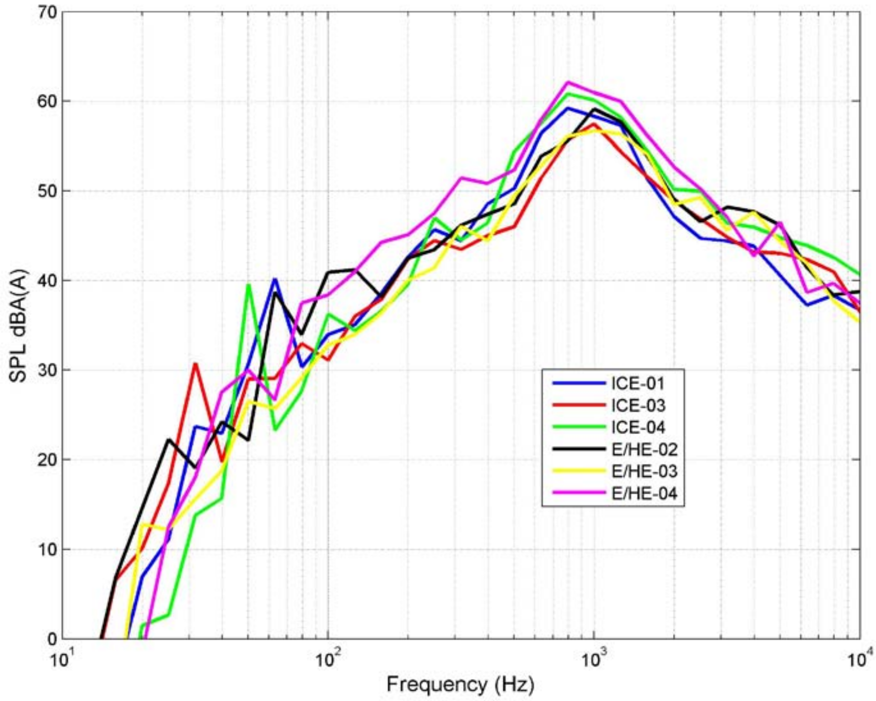


Figure 3.6: One-third octave spectra corresponding to the maximum noise level at a pass-by speed of 20 km/h

Considering the results solely at the time corresponding to the maximum pass-by noise level takes no account of any changes in the vehicle noise signature with time.

The upper plot in Figure 3.7 shows the time history of the noise levels for one of the ICE and one of the E/HE vehicles at a speed of 20 km/h. The lower plot shows the corresponding one-third octave band spectra at the instance at which the vehicles were typically detected, which corresponds to the black line at 17.25 seconds in the upper plot. Were the spectra to be plotted at other instances in the time history, the spectral shape is similar albeit that the individual dB(A) values will differ.

For the time instant considered in Figure 3.7, despite being quieter overall the ICE vehicle is louder below 60 Hz, while the E/HE vehicle is louder in the 1-2 kHz range. These comparative trends in frequency between ICE and E/HE vehicles are fairly consistent across those vehicles tested in the study at speeds of 20 km/h and greater. As already noted, at 7-8 km/h the vehicle noise is too close to the background to allow for meaningful interpretation of the spectral content.

Despite these small differences in the frequency spectra both types of vehicle sound very similar during steady speed pass-bys at 20 km/h. This is indicated later in Table 4.3 and Table 4.4 where it is shown that, from the subjective assessments, the percentage of participants aware of each vehicle type, in a rural environment, is broadly similar.

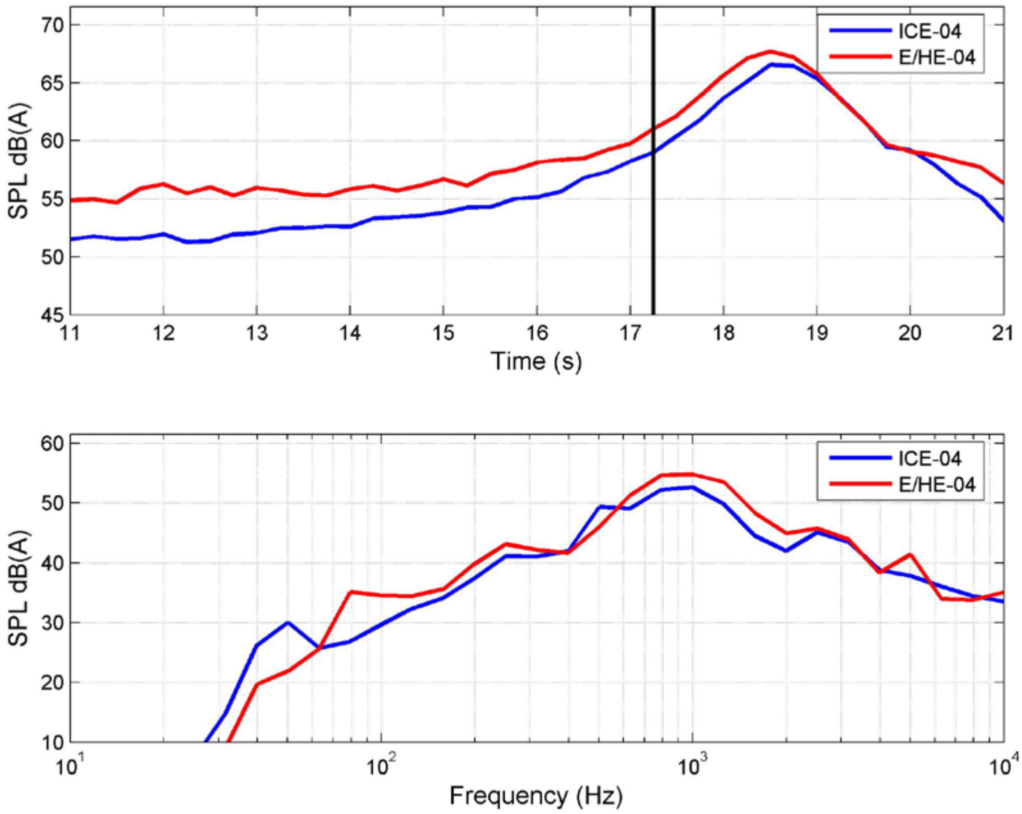


Figure 3.7: Time history and 1/3rd octave spectra for ICE-04 and E/HE-04 at 20 km/h

Summary of findings from measurement programme

Steady speed pass-by: At the lowest speeds where powertrain noise is the dominant source then based on a limited sample of vehicles, the results indicate that E/HE vehicles are, on average, 1 dB(A) quieter than ICE vehicles. It is noted that background noise levels at these speeds were typically only 3 dB(A) below the noise level of the vehicles.

Put into context, a 3 dB(A) increase in the noise level will be detectable by an adult with normal hearing.

The results for one of the ICE vehicles indicate that some of the latest model ICE vehicles can be at least as quiet as E/HE vehicles at steady speed.

Any move to increase the audibility of electric vehicles would also potentially have to take into account not only all new quiet ICE vehicles but possibly recent models already within the current vehicle fleet. It may therefore be necessary to develop a limit value below which a vehicle is considered to be quiet. It is considered unlikely that models already within the vehicle fleet would be addressed, unless existing type approval noise data is sufficient to identify a quiet vehicle.

Summary of findings from measurement programme (Continued...)

At higher speeds, the range across all vehicles, and between vehicle categories, has been shown to be more consistent as may be expected as tyre/road noise becomes the dominant source. The spread at higher speeds is affected by tyre size; larger tyres will have a larger contact patch and therefore are more likely to be noisy. At these higher speeds the E/HE vehicles tested are not noticeably quieter than their ICE counterparts.

Pull-away from rest: The results show E/HE vehicles can, over the initial period of acceleration, be marginally quieter than their ICE counterparts but after the first 5m both vehicle types (with the exception of ICE-02, which is a van) have broadly similar noise levels.

Comparison of noise characteristics: Peaks in the pass-by noise spectra below 100 Hz, relating to exhaust noise, are observed for ICE vehicles. These peaks aside, there does not appear to be any significant difference between the spectral content of ICE and E/HE vehicles, and as such nothing that suggests a pedestrian would clearly be able to differentiate between vehicle types.

Despite small differences in the frequency spectra both types of vehicle sound very similar during steady speed pass-bys at 20 km/h.

3.3 Examples of practical measurements of E/HE vehicle noise from other studies

A review of literature has identified a number of separate studies looking at practical measurements of noise from E/HE vehicles. These are summarised below.

Japanese measurements have been reported (JASIC, 2009) comparing an unidentified HE vehicle running in electric mode with two unidentified ICE vehicles at speeds from 0-30 km/h. Measurements were taken at a kerbside microphone position using the equivalent noise level L_{Aeq}[4] rather than the maximum noise level L_{Amax} as used in the TRL study. It is noted that the test location was such that background noise levels were of the order of 25 dB(A), significantly below those observed in the TRL study. When stationary, the HE vehicle was approximately 20 dB LA_{eq} quieter than the ICE vehicles. It was observed that the slower the speed of the vehicle, the greater the noise level difference when compared to the ICE vehicles. At 10 km/h the difference was approximately 6 dB LA_{eq}. At speeds of 15-20 km/h and above, there was only a small difference in level observed, suggesting that tyre/road noise was most likely the dominant source at these speeds.

[4] L_{Aeq} is the equivalent continuous A-weighted noise level over a given time period, i.e. the equivalent continuous noise level of a steady sound that has, over the given time period, the same energy as the fluctuating sound in question. It is a time-averaged level.

NHTSA have reported practical measurements of three different HE vehicles and their equivalent ICE versions performing different manoeuvres (reversing, slowing, steady-speed pass-by, accelerating from stationary and stationary) at different speeds (NHTSA, 2010). Measurements were taken at several microphone positions. At the closest position (approximately 3.5m from the centre of the running lane) for the steady speed pass-by measurements, at 6 mph (approximately 10 km/h), the HE vehicles were between 2- 9 dB(A) quieter than their ICE equivalents (in terms of maximum level, L_{Amax}). At 10 mph, the E/HE were between 1 and 5 dB(A) quieter, whilst at higher speeds the difference was less than 1 dB(A). For vehicles accelerating from stationary, the HE vehicles were from 0.1-1.9 dB(A) quieter than their ICE equivalents.

Considering the HE vehicle most comparable to that in the TRL study, then for the steady speed measurements, at 6 mph this was 9 dB(A) quieter than the ICE equivalent and 5 dB(A) quieter at 10 mph. Noise levels between the two vehicles converged at speeds of 20 mph and above. At the lowest speed, the HE vehicles were considerably quieter than those in the TRL study. It is noted that the American study had a significantly lower background noise level of the order of 30-35 dB(A), achieved by taking measurements at night.

Sandberg, Goubert and Mioduszewski (2010) reported that BRRC (the Belgian Road Research Centre) conducted practical measurements using a Toyota Prius and some ICE vehicles for a vehicle speed of 20 km/h. Whilst no precise information is given regarding the test setup or road surface, there was found to be almost no difference in noise levels for the Prius between operating in fully electric and ICE modes. It was concluded that at this speed, the Prius emits mainly tyre/road noise. Measurements were also conducted using a 2004 Volvo V50 with a 2 litre turbo diesel engine and a 2004 Renault Espace with a 3.5 litre V6 petrol engine. In each case, two driving modes were tested, one at a constant speed of 20 km/h in 2nd gear and one coasting at 20 km/h with the engine idling. For each vehicle, the difference in noise level between the two modes was of the order of 1 dB(A). It was concluded that the engine noise at 20 km/h for these vehicles was far below the tyre/road noise at that speed and would be almost impossible to hear.

The results from these studies support the findings from the TRL study but demonstrate the importance of taking measurements with background noise levels as low as possible.

4 Subjective test programme

To determine the audibility of E/HE vehicles to vision-impaired pedestrians, a subjective test programme involving 10 vision-impaired participants was devised. As this was a small-scale trial, it is noted that there was no attempt to achieve a balance in terms of gender or any particular distribution of ages, or hearing capabilities, i.e. the vision-impaired participants were not representative of that part of the population suffering visual impairment.

The test programme comprised three parts as follows:

- *Part 1:* A short discussion to provide insight into the level of visual impairment, typical pedestrian behaviour and opinion on what could potentially be done to improve audibility or awareness of E/HE vehicles.
- *Part 2:* A standard audiometric test to determine the vision-impaired participants' level of hearing.
- *Part 3:* A laboratory-based subjective assessment of vehicle noise where the vision-impaired participants were required to listen to a short series of audio samples of vehicles (both E/HE and ICE) moving at different speeds/performing different manoeuvres and identify when they became aware of the presence of the vehicles. This exercise assumed that, for the most part, the vision-impaired participant was stood at the kerbside, as if waiting to cross the road. A final audio sample played to the vision-impaired participants at the very end of the trial was included to gauge opinion on an 'electric vehicle with added sound'.

4.1 Part 1: Discussion session

The discussion session was structured around a series of specific questions, designed to provide an insight into the level of visual impairment and typical pedestrian behaviour of the vision-impaired participants, but also to provide a better understanding of the issues generally affecting vision-impaired pedestrians. The specific questions are listed in Section B.1 of Appendix B, together with the detailed responses provided by each vision-impaired participant. The following paragraphs provide an overview of the responses.

- *Level of visual/aural impairment:* Half of the vision-impaired participants had suffered visual impairment their whole lives. Where vision-impaired participants still had a degree of residual vision, this was generally restricted to being able to distinguish between light and dark. Only one vision-impaired participant wore a hearing aid. Three of the vision-impaired participants were accompanied by guide dogs.
- *Selection of crossing locations:* In terms of what influences the vision-impaired participants' choice of crossing location, the common preference was to use official pedestrian crossing points such as pelican crossings. The presence of tactile paving was also an important feature for identifying crossing points. Away from pedestrian crossings, behaviour varied between subjects, but selecting locations where traffic noise is not masked by other background noise was common, so as to be able to clearly identify approaching traffic.

- *Potential hazards:* The range of identified potential hazards when crossing the road commonly included traffic (particularly in the vicinity of junctions), inattentive drivers, bicycles and other quiet vehicles, and parked vehicles. For two of the vision-impaired participants, background noise sources were noted as being a possible hazard because of the potential for masking vehicle noise; these included both manmade (building works, aircraft noise, etc.) and environmental (strong wind, heavy rain, etc.) sources.
- *Car parks:* The issue of navigating through car parks was raised, from the perspective where the individual has not arrived as a passenger in a vehicle and is therefore not in the company of a sighted individual; such a situation might be encountered if the individual was going to an out-of-town supermarket. Where car parks are familiar, the vision-impaired participants were found to use designated footpaths through/round the car park and the associated designated internal crossing points as much as possible. In unfamiliar situations, the vision-impaired participants were generally accompanied.
- *Use of audio cues:* When crossing the road, five of the vision-impaired participants said that audio cues from pelican crossings or any other audible beeping at crossings was useful, and one vision-impaired participant claimed that they found rotating cones (devices fitted on pedestrian-operated push button controls which can be felt by vision-impaired people as a signal that the lights are on green for them to cross) more useful than any audio cue at crossings. Audio cues relating to traffic were also mentioned, with vision-impaired participants listening for traffic patterns/noise to judge what the traffic is doing and whether it is stopping.
- *Use of visual cues:* The vision-impaired participants stated that they do not rely on visual cues, although one vision-impaired participant with residual vision stated that they can see the illuminated red/green men at pedestrian crossings and the yellow wait sign but only if it is dark.
- *Influences on crossing behaviour:* Their crossing behaviour is influenced by any sounds that can be heard that indicate how the traffic is behaving or how busy the road is. These include engine sounds of stopped vehicles, deceleration and pass-by noise. They are largely reliant on audio cues (and guide dogs if applicable). Audio cues are more important than visual cues to the majority of vision-impaired participants.

  For vision-impaired participants who had not been vision-impaired all their life, their crossing behaviour has been influenced by their confidence and learning to judge speed, distances and traffic behaviour.
- *Improving the audibility of electric vehicles:* The majority of the vision-impaired participants said that they would prefer electric vehicles to sound like a “proper” or “traditional” vehicle, i.e. a petrol/diesel engine. Alternatively, the sound should be something that can’t be confused with anything else. One of the vision-impaired participants recognised that people would say that any sound that an electric vehicles makes would be considered a problem and another stated that trolley buses were silent.

- *Use of non-audible warning technologies:* Vision-impaired participants were asked whether non-audible technologies, e.g. vibrations through a white stick or mobile phone, might be of use if these were developed in the future. The majority expressed the view that an alerting technology held by the pedestrian would be beneficial but the preference was for the alert to be audible rather than a vibration.

4.2 Part 2: Audiometric testing and participant overview

The invitation to participate in the trial was distributed through organisations associated with the vision-impaired. As this was a small-scale trial, there was no attempt to achieve a balance in terms of gender or any particular distribution of ages, or hearing capabilities.

Each vision-impaired participant undertook a Hughson-Westlake automatic audiometric test (Carhart & Jerger, 1959) to assess their level of hearing. During the test, the vision-impaired participants were played a set of pure tones in each ear at the following frequencies: 125, 250, 500, 750, 1000, 2000, 3000, 4000, 6000 and 8000 Hz, and required to identify when they were able to hear each tone by pressing a handheld trigger. The initial volume of each tone was 50 dB and this increased or decreased by increments of 5 or 10 dB depending on the response of the vision-impaired participant.

To assess the vision-impaired participants' level of hearing, the audiometer assigned scores to the responses at each frequency and these scores are summed at 1, 2, 3, 4 and 6 kHz to determine the hearing level of each ear. Mild hearing impairment and poor hearing are identified if these scores exceed certain levels (shown in the 6th and 7th column of the table) which are dependent on age and gender.

Table 4.1 summarises the summed scores of the audiometric tests for each vision-impaired participant together with information on their age and sex. The table also states whether or not the participants use a guide dog.

The majority of the vision-impaired participants were males over 50 years of age. The two female vision-impaired participants were both under 50 years of age. It is observed that of the 10 vision-impaired participants, six of these were found to have unimpaired hearing, three were found to suffer only mild hearing impairment in one or both ears, and one suffered poor hearing in their left ear and mild hearing impairment in the right ear.

It is noted that the vision-impaired participant wearing hearing aids wore them during the trial.

4.3 Part 3: Subjective assessment of vehicle noise samples

The vision-impaired participants were played a series of audio samples of vehicles (both E/HE and ICE) moving at different speeds/performing different manoeuvres with the objective being to identify when they became aware of the presence of the vehicles and if they were able to distinguish the vehicle type. The exercise assumed that, for the most part, the vision-impaired participant was a pedestrian stood at the kerbside, as if waiting to cross the road.

The audio sequences were derived from the real-time audio recordings taken during the practical measurement programme described in Chapter 3.

Table 4.1: Hughson-Westlake automatic audiometric test results

Vision impaired participant	Age	Sex	Ear		Lower threshold for mild hearing impairment*	Lower threshold for poor hearing*	Comments on hearing test	Guide dog user
			Left	Right				
1	31	Male	105	100	82	132		No
2	53	Male	195	155	165	240		No
3	57	Male	325	195	190	269	Suffers from a fluid issue in his left ear	No
4	60	Male	130	105	217	296		Yes
5	65	Male	150	140	235	311		No
6	67	Male	195	125	235	311		Yes
7	71	Male	105	105	235	311		No
8	87	Male	205	200	235	311	Hearing aids in both ears, could not hear pure tones > 3kHz at 80dB in both ears	No
9	31	Female	90	65	63	105		Yes
10	43	Female	30	50	80	134		No

* Threshold is age and gender dependant. Subject has stated level of hearing impairment in a particular ear if the score for that ear exceeds these values

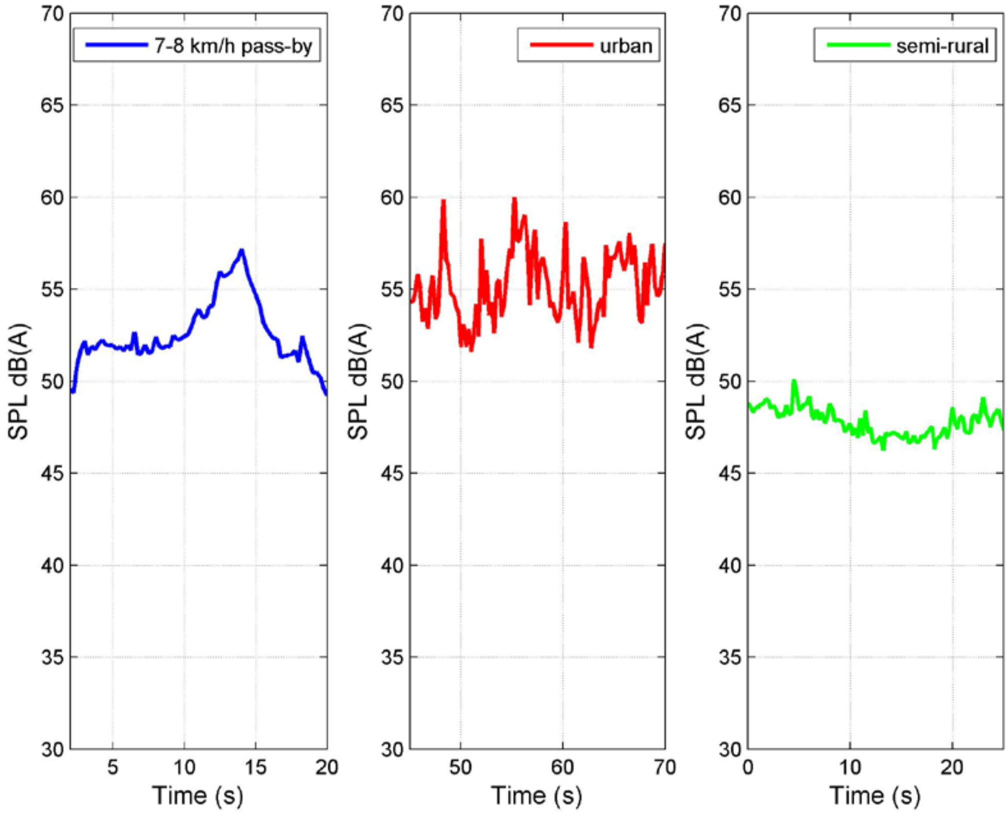
Background noise levels on the TRL test track were both low and less representative of the types of background noise at locations where vision-impaired pedestrians are likely to cross the road, e.g. there was little noise other than birdsong and low-level traffic noise from local roads in the vicinity of the test track. Audio sequences with this type of background will be referred to as being in a 'semi-rural' environment. The sequences were not adapted to take account of any variations in background noise level on the different days of the test programme.

In order to create more representative scenarios, the 'semi-rural' environment audio sequences were supplemented with background recordings of pedestrian activity. Audio sequences with this type of background will be referred to as being in an 'urban' environment.

It is noted that none of the audio sequences included the presence of other traffic in order to achieve the specific objectives of the project, i.e. to identify whether E/HE vehicles are audibly more difficult to detect than ICE vehicles.

Appendix C contains a summary of the audio sequences in terms of the type of background level and the vehicle composition

Figure 4.1 illustrates typical noise levels for the different background environments, compared to the noise levels for a 7-8 km/h pass-by for one of the noisier (ICE) vehicles in the test programme (the peak in the left-hand plot corresponds to the vehicle passing the kerbside measurement microphone).



(a) Pass-by noise (b) Urban background noise (c) Semi-rural background noise

Figure 4.1: ICE vehicle pass-by noise at 5km/h and typical background noise levels for the 'urban' and 'semi-rural' environments used in the audio samples

It is observed that the 'urban' background noise level fluctuates over time, but is on average 5 dB(A) above the typical 'semi-rural' background level. While the vehicle pass-by noise is always above the 'semi-rural' background level, it may be lower than the 'urban' level at low speeds; this would make the ICE vehicle difficult to detect in such conditions and even more so if it was a quieter ICE vehicle.

The study comprised the following three broadly defined scenarios, each including four audio sequences of different combinations of vehicles operating at different speeds and/or performing different manoeuvres. Each scenario was repeated for both 'semi-rural' and 'urban' environments.

- *Scenario 1: Traffic lights/junction.* This included vehicles pulling away from rest and vehicle pass-bys at 20-50 km/h.
- *Scenario 2: Car park.* This included vehicle manoeuvring out of parking spaces (both forwards and in reverse), vehicles pulling away from rest, and vehicle pass-bys at 7-8 km/h.

- *Scenario 3: Road with speed limit of 30 mph.* This included vehicle pass-bys at 20-50 km/h.

For the pass-by measurements, only traffic movement from right to left was considered, i.e. with vehicles in the running lane nearest to the vision-impaired participant in the equivalent real-life scenario. The car park was less representative of normal conditions since the vehicle pulled out of the parking space in only one direction, regardless of whether the vehicle was reversing or driving forwards out of the space.

The audio samples included a larger number of ICE vehicles than E/HE vehicles so as to be more representative of what a pedestrian would encounter at the roadside.

Based on when the vehicles passed the microphones during the practical measurements, it was possible to use the vision-impaired participant's response times to determine the effective physical proximity of the vehicles to the subject at the point of audibility.

4.3.1 Assessment of vehicle manoeuvres at steady speeds and under low acceleration (Scenarios 1 and 3)

Due to the small sample sizes and the demographic of the participants not being representative of that part of the population suffering visual impairment, the results provide only an initial indication of the possible risks to vision-impaired pedestrians. As such, they should not be taken to necessarily represent the risks at a national level.

The audio samples assume the equivalent real-life scenario of the vision-impaired participant being stood at the kerbside waiting to cross the road.

The results have been analysed to determine the position of the vehicle relative to the vision-impaired participant at the point of detection. It is assumed that in the equivalent real-life scenario, the point of detection would influence whether or not the participant would choose to step out into the road. If the presence of the vehicle was not detected at all then the vision-impaired participant might choose to cross at any time.

The results are expressed in terms of a variable "risk exposure", based on the assumption that there will always be some element of risk, however small, for crossing pedestrians whenever traffic is present on the road.

Using safe stopping distances as defined in the UK Highway Code (Department for Transport and Driving Standards Agency, 2007), the risk exposure of the vision-impaired participant waiting to cross the road has been considered to be "increased" if either the vehicle was detected at a distance less than the safe stopping distance or the vehicle was not detected at all.

It is noted that modern vehicles are capable of stopping well within the Highway Code stopping distances, so that even if a vehicle is within the safe stopping distance, avoiding action could still be possible if a pedestrian stepped off the kerb.

In each case, the *total number of events* for any mode of operation is derived from the product of the number of vehicles performing a specific manoeuvre at a given speed and the total number of vision-impaired participants in the trial.

Table 4.2 summarises the results considering all operational pass-by and acceleration modes as a single dataset.

Table 4.2: Percentage of events with increased risk exposure for different vehicles types

	Total events	% of events with increased risk exposure		
		'Semi-rural' environment	'Urban' environment	All environments
ICE vehicles	440	12.3 %	22.3 %	15.0%
E/HE vehicles	240	17.3%	28.9%	21.7%
Relative risk for E/HE vehicles		1.4	1.3	1.4

Based upon a sample of only 8 vehicles (4 E/HE and 4 ICE) the results suggest that

- In a 'semi-rural' environment, the possibility of increased risk exposure is 1.4 times greater for E/HE vehicles than ICE vehicles, irrespective of the vehicle speed or manoeuvre
- In an 'urban' environment, the possibility of increased risk exposure is 1.3 times greater for E/HE vehicles, with the reduction in relative risk being due to the increased level of background noise and the lower detectability of quiet ICE vehicles in such environments
- Irrespective of the background environment, the study indicates that the possibility of increased risk exposure is 1.4 times greater for E/HE vehicles than for ICE vehicles

Table 4.3 and Table 4.4 present the results for ICE vehicles and E/HE vehicles respectively for those vehicle manoeuvres where the equivalent real-life scenario was the vehicle either driving past the participant at a steady speed or pulling away from rest. The results are summarised in the following paragraphs.

- Considering only steady-speed pass-by modes, then at the lowest speed (7-8 km/h) in a 'semi-rural' environment, the possibility of increased risk exposure was four times greater for E/HE vehicles than for ICE vehicles (40% compared to 10%). For one of the E/HE vehicles, 80% of the vision-impaired participants either failed to hear the vehicle at all or only detected it after it had driven past where they were standing.
- In an 'urban' environment with vehicles travelling at 7-8 km/h, the possibility of increased risk exposure was twice as great for E/HE vehicles (80% compared to 40%). For the E/HE vehicles, the participants failed to detect the vehicle at all 70% of the time; for the ICE vehicles, the participants heard the vehicle when it was less than 5m away in 70% of cases, while for 15% of the events of participants either failed to hear the vehicle at all or only detected it after it had driven past where they were standing.

Table 4.3: Subjective test results for audio samples involving ICE vehicles (cars and vans)

Operation/ speed	Safe stopping distance*	'Semi-rural' environment			'Urban' environment		
		Total no. of events	No. of events with increased risk exposure	% of events with increased risk exposure	Total no. of events	No. of events with increased risk exposure	% of events with increased risk exposure
Pass-by, 7-8 km/h	1.0 m	30	3	10.0%	20	8	40.0%
Pass-by, 20 km/h	7.0 m	70	14	20.0%	10	5	50.0%
Pass-by, 30 km/h	12.0 m	70	10	14.3%	40	14	35.0%
Pass-by, 50 km/h	23.0 m	70	10	14.3%	20	0	0.%
Acceleration, 0.5 ms^{-2}	N/A	50	1	2.0%	10	1	10.0%
Acceleration, 1 ms^{-2}	N/A	20	0	0.0%	20	0	0%
ALL MODES	N/A	310	38	12.3%	130	28	22.3%

* Stopping distances at 30 km/h and 50 km/h are taken from the UK Highway Code. Stopping distances at 5 and 20 km/h are extrapolated from the published values from 20-70 mph.

Table 4.4: Subjective test results for audio samples involving E/HE vehicles (cars and vans)

Operation/ speed	Safe stopping distance*	'Semi-rural' environment			'Urban' environment		
		Total no. of events	No. of events with increased risk exposure	% of events with increased risk exposure	Total no. of events	No. of events with increased risk exposure	% of events with increased risk exposure
Pass-by, 7-8 km/h	1.0 m	20	8	40.0%	20	16	80.0%
Pass-by, 20 km/h	7.0 m	40	7	17.5%	10	2	20.0%
Pass-by, 30 km/h	12.0 m	0	0	N/A	10	4	40.0%
Pass-by, 50 km/h	23.0 m	40	6	15.0%	20	0	0%
Acceleration, 0.5 ms^{-2}	N/A	30	4	13.3%	30	4	13.3%
Acceleration, 1 ms^{-2}	N/A	20	1	5.0%	0	0	N/A
ALL MODES	N/A	150	26	17.3%	90	26	28.9%

* Stopping distances at 30 km/h and 50 km/h are taken from the UK Highway Code. Stopping distances at 5 and 20 km/h are extrapolated from the published values from 20-70 mph.

The increase in the possibility of increased risk exposure (for both vehicle categories) in 'urban' areas is to be expected due to the nature of the background noise in 'urban' environments, which is likely to be louder than in 'semi-rural' conditions and more variable in nature.

At higher pass-by speeds in a 'semi-rural' environment, the possibility of increased risk exposure was generally observed to be similar for both vehicle types, as might be predicted from the noise measurements reported in Section 3.

- In the 'urban' environment at speeds of 30km/h and above, the possibility of increased risk exposure for both vehicle types was generally similar. However, at 20km/h, the results suggest that the increased risk exposure was significantly greater from ICE vehicles (50% compared to 20% for E/HE vehicles). However, the results are derived from events involving only a single vehicle of each type passing each vision-impaired participant once. As such, it is not possible to draw any robust conclusions from these numbers. One potential reason for the differences is that the ICE vehicle may have been particularly quiet and compared against a noisier E/HE vehicle, or that the ICE vehicle may have been operating at very low revs in the selected gear during the vehicle pass-by.
- In the 'semi-rural' environment alone, the possibility of increased risk exposure was 6 times greater for E/HE vehicles accelerating at $0.5ms^{-2}$ than for ICE vehicles accelerating at the same rate. As the acceleration rate increased to $1ms^{-2}$, the ICE vehicles were detected by all vision-impaired participants outside of the safe stopping distance, while only 1 participant experienced increased risk exposure from the accelerating E/HE vehicles.
- The results suggest that the possibility of increased risk exposure posed by vehicles pulling away from rest is significantly less than that when the vehicles are passing by at steady speed. However, it must be recognised that the vision-impaired participants were, in effect, stood only 10m away from the stationary vehicles before they pulled away.

Considering the results in terms of those vision-impaired participants with some (mild) level of hearing loss in one or both ears, the likelihood of increased risk exposure for either vehicle category was not observed to be any greater than that for vision-impaired participants with normal hearing. However, the vision-impaired participant with poor hearing generally had greater difficulty identifying the presence of the vehicles at steady speeds of 30 km/h and below, regardless of the environment and was more at risk from vehicles accelerating at low-speed in a rural environment.

4.3.2 Assessment of vehicle parking manoeuvres (Scenario 2)

Due to the small sample sizes and the demographic of the participants not being representative of that part of the population suffering visual impairment, the results provide only an initial indication of the possible risks to vision-impaired pedestrians. As such, they should not be taken to necessarily represent the risks at a national level.

The audio samples assume the equivalent real-life scenario of the vision-impaired participant being at a point two parking spaces way from the manoeuvring vehicle. As such, the assessment of the subjective responses has been approached in a different manner to that for the other vehicle operations. The focus has been solely on whether the participant was able to detect the presence of the vehicle during the manoeuvre and not linked to the position of the vehicle relative to the participant at the point of detection.

Table 4.5 and Table 4.6 summarise the results for ICE and E/HE vehicles respectively.

Table 4.5: Subjective test results for the detectability of ICE vehicles performing parking manoeuvres

Vehicle direction	'Semi-rural' environment			'Urban' environment		
	Total events	No. of vehicles Detected	% Detected	Total events	No. of vehicles detected	% Detected
Forwards	10	10	100%	10	10	100%
Backwards	20	20	100%	---	---	---

Table 4.6: Subjective test results for the detectability of E/HE vehicles performing parking manoeuvres

Vehicle direction	'Semi-rural' environment			'Urban' environment		
	Total events	No. of vehicles Detected	% Detected	Total events	No. of vehicles detected	% Detected
Forwards	10	9	90%	---	---	---
Backwards	10	10	100%	10	6	60%

It is observed that the number of events in the parking scenarios is low, especially for the urban scenarios. The results provide only an initial indication of the potential risks to vision-impaired pedestrians and should not be taken to necessarily represent the risks at a national level.

In a 'semi-rural' rural background environment, the vehicles were detected by almost all of the vision-impaired participants. Success rates for the electric vehicles in an 'urban' environment were reduced, but the majority of vehicles were detected. It must be noted that detection was not necessarily due to the participant hearing the vehicle engines/motors but rather either tyre scrub during turning or gravel in the tread of the tyres.

4.3.3 Assessing the vehicle type from pass-by noise

As already noted, the vision-impaired participants were asked whether they were able to identify the type of vehicle passing them at the kerbside for each vehicle detected. It is noted that while many of the vision-impaired participants came from within the London area, very few had any previous experience of the current fleet of electric vehicles, being only aware of milk floats and electric mobility scooters/wheelchairs.

Table 4.7 to Table 4.9 summarise the responses from the vision-impaired participants for the different operational modes, in terms of whether they were able to correctly distinguish between whether the vehicle was an ICE or E/HE vehicle. The table also identifies where the vision-impaired participants were undecided or whether they did not offer any comment.

Table 4.7: Results of vehicle type assessment – steady-speed pass-by modes

Vehicle type	'Semi-rural' environment				'Urban' environment			
	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response
ICE vehicles	240	72.5%	16.7%	0.8%	90	57.8%	20.0%	2.2%
E/HE vehicles	100	32.0%	18.0%	8.0%	60	30.0%	6.7%	30.0%

Table 4.8: Results of vehicle type assessment – pull-away from rest modes

Vehicle type	'Semi-rural' environment				'Urban' environment			
	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response
ICE vehicles	50	80.0%	11.4%	2.9%	30	83.3%	10.0%	0%
E/HE vehicles	70	72.0%	16.0%	16%	30	70.0%	16.7%	0%

Table 4.9: Results of vehicle type assessment – parking modes

Vehicle type	'Semi-rural' environment				'Urban' environment			
	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response	Total events	% of vehicles correctly identified	% with vehicle type unknown	% with no response
ICE vehicles	30	56.7%	13.3%	6.7%	10	80.0%	20.0%	0.0%
E/HE vehicles	20	35.0%	10.0%	50.0%	10	50.0%	20.0%	20.0%

It is noted that the percentages shown in the Tables do not add up to 100%; the difference is that percentage of vehicles that were incorrectly identified, e.g. an E/HE vehicle was identified by the participant as an ICE vehicle.

Under steady-speed conditions, vision-impaired participants were more than twice as likely to correctly identify ICE vehicles as E/HE vehicles in a rural scenario and almost twice as likely to correctly identify the vehicles in an urban scenario. However, at the lower speeds the rate of correct detection of the quietest ICE vehicle was comparable to that of the E/HE vehicles.

When the vehicles were accelerating from stationary, the vision-impaired participants were far more easily able to identify both vehicle types. Detection rates for EH/E vehicles were only 8-13% below that for ICE vehicles depending upon the environment.

For the parking measurements, identification rates for the E/HE vehicles were no more than 50%. However, the numbers of events are very small, so no robust conclusions can be drawn from these results.

Familiarity with the different vehicle types will have had an impact upon the results. One of the comments made in relation to this aspect of the trial was that the perception of what an electric vehicle might actually sound like is likely to affect judgement when distinguishing between vehicles. Several of the vision-impaired participants had not previously encountered electric vehicles on public roads other than milk floats or electric mobility scooters/wheelchairs. Improved public awareness of the noise from E/HE vehicles is expected to improve the correct identification of electric vehicles in the different operating modes.

4.3.4 Feedback on electric vehicles with added sound

The final part of the trial involved the vision-impaired participants listening to an audio sample of an electric vehicle with added sound performing two manoeuvres: a steady-speed pass-by and pulling away from rest. The added sound has been developed by an individual vehicle manufacturer and demonstrated to TRL and DfT using one of the manufacturer's hybrid electric vehicles. The added sound comprises a low-frequency (600 Hz) rumble and a high-frequency (2,500 Hz) whistle at steady-speed, with the former changing in pitch as the vehicle speed increases; the sound starts when the vehicle pulls away from rest. An additional sound is emitted at the instant that the vehicle pulls away, so that anybody in proximity to the vehicle is aware that the vehicle is about to move off.

Section B.3 of Appendix B summarises the responses of the vision-impaired participants to the audio sample. Overall, the reaction was mixed, with only a limited number considering that the added sound was either reasonable or made the vehicle more detectable.

The noise emitted when the vehicle pulls away from rest was generally better received and considered to be more distinctive than the steady-speed pass-by noise, which was considered to be too quiet.

When asked how this particular set of added sounds could be changed/improved (volume aside), 60% of the vision-impaired participants considered the sound was ok although several stated that they would still prefer the added sound to be like that of a similar conventional engine. It was also considered that pedestrians with hearing impairment may not be able to hear the high frequency noise.

4.3.5 Participant opinion on the subjective trial

At the conclusion of the tests, the vision-impaired participants were asked to provide feedback on Part 2 of the trial, i.e. the audio samples. The detailed comments are collated in Section B.2.

Several of the vision-impaired participants found the presence of traffic on local roads in the vicinity of the test track distracting based on the tasks that they had been asked to perform. Additionally, variations in the level of background noise between different samples or between the samples and the audio linking the different samples was distracting for some people, making it obvious when certain samples started. This was a consequence of the different audio samples having been recorded at different times. Two of the vision-impaired participants noted that they found the tasks easier because vehicles were only travelling in one direction.

Several of the vision-impaired participants were surprised at just how quiet some of the vehicles were and were of the opinion that they had potentially missed some of the vehicles or detected them too late to avoid collision.

A number of comments were also received during the organisation of the subjective trial, the invitation for which broadly outlined the different scenarios to be investigated. The most common observations were the lack of realism caused by performing the trials in a laboratory and not in the presence of actual vehicles, the absence of other traffic, and the limited range of background noise scenarios.

In the case of the lack of other vehicles, it is noted that the scenarios were designed to achieve the specific objectives of the project, i.e. to identify whether E/HE vehicles are audibly more difficult to detect than ICE vehicles and therefore whether they pose more of a safety risk to vision-impaired pedestrians. Therefore, the scenarios were not designed to be totally true to life since excessive background noise and other vehicles would prevent meaningful comparisons.

In the case of background noise scenarios, factors such as other traffic, high levels of pedestrian activity and noise caused by wind/heavy rain were some of the suggestions proposed to improve the realism of the trials.

Real life testing has been identified as an important next step for any future subjective testing.

Summary of findings from subjective audio trials

A subjective assessment trial comprising 440 ICE vehicle/vision-impaired participant interactions and 240 E/HE vehicle/vision-impaired participant interactions has been undertaken based around 8 vehicles (4 E/HE and 4 ICE) and 10 vision-impaired participants.

The sample sizes are small and as such, the results provide only an initial indication of the possible risks to vision-impaired pedestrians and should not be taken to necessarily represent the risks at a national level.

Results are considered in terms of “risk exposure”, based on the assumption that there will always be some element of risk for crossing pedestrians whenever traffic is present on the road. Risk exposure was deemed to be ‘increased’ if the presence of the vehicle was detected at a distance less than typical safe stopping distances or not detected at all.

Summary of findings from subjective audio trials

The results indicate that the likelihood of increased risk exposure is 1.4 times greater in a 'semi-rural' environment for E/HE vehicles than ICE vehicles (17.3% compared to 12.3%), irrespective of vehicle speed or manoeuvre, and 1.3 greater in an 'urban' environment (28.9% compared to 22.3%). Irrespective of the background environment, the study indicates that the likelihood of increased risk exposure was 1.4 greater for E/HE vehicles than ICE vehicles (21.7% compared to 15%).

For low-speed pass-bys in a 'semi-rural' environment the likelihood of increased risk exposure was four times greater for E/HE vehicles than for ICE vehicles. In an 'urban' environment the likelihood of increased risk exposure was twice as great for E/HE vehicles.

The increase in the likelihood of increased risk exposure (for both vehicle categories) in 'urban' areas is to be expected due to the nature of the background noise in 'urban' environments, which is likely to be louder than in 'semi-rural' conditions and more variable in nature. At higher pass-by speeds in a 'semi-rural' environment, the likelihood of increased risk exposure was generally observed to be similar for both vehicle types, as might be predicted from the results of the practical measurements.

In the 'semi-rural' environment alone, the possibility of increased risk exposure was 6 times greater for E/HE vehicles accelerating at low rates than for ICE vehicles accelerating at the same rate. At higher acceleration rates, the majority of vision-impaired participants detected all of the vehicles. The results suggest that the level of risk posed by vehicles pulling away from rest is significantly less than that when the vehicles are passing by at steady speed.

For vehicles performing parking manoeuvres in a 'semi-rural' background environment, the vehicles were detected by the almost all of the participants. Success rates for the electric vehicles in an 'urban' environment were reduced, but the majority of vehicles were detected. Detection was not necessarily due to the participants hearing the vehicle engines/motors but rather either tyre scrub during turning or gravel in the tread of the tyres.

Under steady-speed conditions, participants were more than twice as likely to correctly identify ICE vehicles as E/HE vehicles in a rural scenario and almost twice as likely to correctly identify the vehicles in an urban scenario. When the vehicles were accelerating from stationary, subjects were far more easily able to identify both vehicle types. For the parking measurements, identification rates for the E/HE vehicles were no more than 50%.

4.4 Examples of subjective assessments of E/HE vehicle noise from other studies

A review of literature has identified a number of separate studies looking at subjective assessments of noise from E/HE vehicles. These are summarised below.

Rosenblum (2008) reported on subjective laboratory assessments of the audibility of hybrid vehicles operating in full electric mode. Subjects were blindfolded (to improve concentration) and then listened to recordings of cars approaching at 5 mph on a test track. A 2004 Honda Accord was used as the ‘not-quiet’ vehicle, while a Toyota Prius was used as the hybrid vehicle. Subjects were able to identify the Accord when it was 36 feet away (equivalent to +4.9 seconds away), but were only able to identify the Prius from a distance of 11 feet (+1.4 seconds away). When background noise was introduced, subjects were unable to identify the Prius until 1.6 feet *after* the vehicle had passed by (-0.2 seconds away), i.e. effectively after the vehicle would have impacted with them. Rosenblum also indicated that at speeds above 15-20 mph, there is sufficient tyre/road noise and aerodynamic noise for vehicles running in full electric mode to be detected.

Work reported by JASIC (2009) on the evaluation of perception of electric vehicles used subjective testing in a laboratory, but with the participant listening to the audio through loudspeakers rather than through headphones. At the lowest speeds, which were of a similar order to those in the TRL tests, detection of the vehicle generally occurred at distances of less than 5 m for a range of different background noise levels. At the lowest background levels, ICE vehicles were detected at distances of over 10 m away, but at the highest levels, the detection distances were similar to those of the hybrid vehicle. At 20 km/h, the detection distances for both vehicle types were similar at all background levels. It was observed that under some background noise conditions, the distance at which the electric vehicles were detected was less than the stopping distance under worst-case conditions.

NHTSA (2010) have reported subjective laboratory assessments using 48 vision-impaired participants who listened to audio recordings of vehicle manoeuvres (reversing, steady speed pass-by at 6 mph and slowing as if to turn) at different speeds through headphones. In low ambient background noise conditions, the ICE vehicles were detected earlier than the HE vehicles regardless of the vehicle manoeuvre. However, in the higher background noise conditions, vehicles were generally detected later, i.e. ‘closer’ to the participant. In the case of the HE vehicle equivalent to that used in the TRL study, in the higher background noise condition, the vehicle may not have been detected within an adequate amount of time to avoid collision; this was not the case in the lower background noise condition.

5 Considerations with respect to improving the audibility of quiet vehicles

Whilst the concerns of organisations associated with the vision-impaired are acknowledged, the results of the current study suggest that whilst there may be a potential risk to vision-impaired pedestrians from E/HE vehicles, particularly in urban environments, the scale of the problem is currently very small. The number of electric vehicles on the market would be required to increase significantly for the accident risk from E/HE vehicles to potentially become a significant issue. However, it is noted that manufacturers are taking steps to independently (i.e. without legislation) increase the audibility of such vehicles which may reduce the potential risk if noise is a significant contributory factor.

Audibility of E/HE vehicles is only a problem at low speeds; at speeds in excess of 20 km/h tyre/road noise replaces powertrain noise as the dominant noise source, at which point, any differences between E/HE and ICE vehicles are negligible. The results of the practical measurements indicate that quiet ICE vehicles generate comparable noise levels to E/HE vehicles and furthermore, do not show any great distinction from E/HE vehicles in terms of spectral characteristics. This is supported by the results of the subjective trial where quiet ICE vehicles travelling at low speeds were no more easily identified by the participants than the E/HE vehicles. The *combined risk* from quiet E/HE and ICE vehicles may provide additional impetus for action.

With further technological advances in engine design, particularly related to ICE vehicles, the risk to pedestrian safety from quiet vehicles is likely to increase further. Any consideration of improving the audibility of E/HE vehicles may also potentially have to take into account future model ‘quiet’ ICE vehicles. This will require the definition of a limit value under specified operating conditions below which any vehicle will be deemed to be ‘quiet’.

The use of such added sounds should assist vision-impaired pedestrians in assessing the position of the vehicle, the direction of travel and the speed and behaviour. The sounds must be discernable under a wide range of background conditions, from quiet rural locations to busy urban environments as well as under adverse environmental conditions when wind/rain noise can potentially mask the noise of approaching traffic.

The means of improving the audibility of electric/hybrid vehicles is currently the subject of work by both researchers and vehicle manufacturers in both the UK and overseas, for example, Lotus Engineering and Warwick University in the UK, General Motors in the USA and Nissan in Japan. This work also frequently involves national organisations associated with visual impairment such as Guide Dogs and JCMBPS (Joint Committee on Mobility of Blind and Partially Sighted People) in the UK and the National Federation of the Blind in the USA. These studies are considering a wide range of options for the types of added sound to be used; consideration is not being given solely to options that reproduce the sound of conventional internal combustion engine vehicles. A number of these systems are ready for market implementation and will be introduced as standard on forthcoming models, e.g. the Nissan Leaf and the Chevy Volt.

It is also known that vehicle manufacturers would prefer not to have added sounds that are common to all quiet vehicles, but rather use sounds that distinguish their particular vehicles from those of their competitors.

The comments regarding improved audibility of electric vehicles collated during the subjective trials (Chapter 4) and discussions with other parties over the course of the project suggest that many people would prefer any added sound to reproduce the noise of a conventional internal combustion engine vehicle.

Whatever options are chosen for use, either voluntarily or mandatorily as a result of future legislation, the sounds will need to be sufficiently distinctive such that they can be readily attributed to the presence of a quiet vehicle, be it either E/HE or ICE.

The following recommendations are therefore considered necessary in establishing whether there is a mandatory need for added sound on quiet vehicles (E/HE and ICE) in the UK and reducing the potential risks to vision-impaired pedestrians:

- An assessment of data within the STATS19 database to determine the accident rates for 'quiet' internal combustion engine vehicles. This will require the definition of a limit value under specified operating conditions below which any vehicle will be deemed to be 'quiet'. Alternatively this will require assumptions regarding the vehicle noise level, e.g. based on type approval level, engine size of vehicles, etc. Current type approval procedures do not provide information on minimum noise levels, but type approval limit values may provide a provisional starting point. Under type approval, vehicles must not generate pass-by noise levels (under a full-throttle acceleration test) in excess of 74 dB(A); selecting those vehicles with a type approval level below, say, 70 dB(A) or a certain percentage of the quietest vehicles at type approval may be possible considerations. ISO (International Organisation for Standardisation) has proposed a test method for determining the minimum noise generated by a motor vehicle; no limit values have been suggested or set. The method is in the process of being adopted as a standard.
- A national campaign to raise public awareness of quiet vehicles amongst drivers and pedestrians. This would involve significant liaison and involvement with national institutions associated with the vision-impaired, as well as organisations associated with other vulnerable road user groups.

  Such a campaign might potentially operate at two levels:

  - *At the point of purchase:* This might be based upon information supplied by the manufacturers. For example, the Plug-in Car Grant letter already requires that dealers must inform consumers that these vehicles may be particularly quiet at 12 mph or less and that extra care should be taken when driving
  - *In the wider public domain:* This would remind drivers of the issue after purchase and also inform pedestrians (including owners of non-electric vehicles) who would not necessarily be exposed to manufacturer's literature. Possible options for this might include advertising campaigns, practical demonstrations, the use of road signs and urban traffic information systems, etc.
- A wider subjective assessment trial, using a greater number of vehicles and a larger number of participants. Such an assessment should take into account a wider range of background noise/environmental noise conditions. For example, detectability in the presence of other traffic, urban background noise sources other than pedestrian noise, wind noise, rain noise, etc. Consideration should be given to whether this can be achieved as a practical trial with vehicles physically driving past subjects

Work in the further development of added sound should not only consider the vehicles in lone operation but should also take into account the potential for noise nuisance/disturbance when vehicles are operating in numbers in restricted environments such as car parks.

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6 Summary and conclusions

DfT commissioned TRL to determine whether the potential safety risk to vision-impaired pedestrians from the increased use of electric and hybrid electric (E/HE) vehicles is real and whether E/HE vehicles are audibly more difficult to detect than their traditional internal combustion engine (ICE) equivalents. An assessment has been undertaken based on a review of accident statistics, a programme of practical testing to measure the noise levels of under different modes of operation, and a limited subjective assessment of the noise involving vision-impaired subjects.

6.1 Conclusions arising from the statistical data review

An analysis of vehicle accident statistics for Great Britain has been undertaken for the period 2005-2008 and shows that:

1. Relative to the number of registered vehicles, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were 30% less likely to be involved in an accident than ICE vehicles (495 accidents compared to 737,655). Introducing vans < 3.5 tonnes GVW into the vehicle group, then E/HE vehicles were 38% less likely to be involved in an accident than ICE vehicles (497 accidents compared to 782,355).
2. Relative to the number of registered vehicles, for the combined vehicle group of passenger cars and car-derived vans, E/HE vehicles were equally as likely to be involved in a collision with a pedestrian as ICE vehicles (61 accidents compared to 63,575). Introducing vans < 3.5 tonnes GVW into the vehicle group, then E/HE vehicles were 10% less likely to be involved in a collision with a pedestrian than ICE vehicles (62 compared to 67,610).
3. While the relative rates are all less than one, comparing the relative rate for E/HE vehicles involved in all accidents (0.62) with the relative rate of E/HE vehicles which collide with a pedestrian (0.90) suggests that although the relative number of E/HE vehicles involved in accidents is smaller, proportionately more of these vehicles hit a pedestrian than ICE vehicles. Considering the combination of passenger cars and car-derived vans only, the relative rates are 0.70 and 1.0. Whilst this potentially supports the perceived increase in pedestrian risk for E/HE vehicles, it may be that the accident rates reflect the usage patterns of E/HE vehicles; total mileages for E/HE vehicles may be lower than ICEs hence the lower overall accident rate, but a higher proportion of their use may be in urban areas, hence the similar pedestrian accident rate to ICEs.

There were only two E/HE accidents involving a collision with a pedestrian who was disabled in some way (CF810) so it is not possible to make a judgement on the perceived risk to vision-impaired pedestrians.

However, none of the relative rates take account of vehicle speed, vehicle manoeuvre or the location of the accident, e.g. whether or not the accident occurred in a built-up area. Additionally, no differentiation is made between fully electric and hybrid electric vehicles.

4. Considering only passenger cars and car-derived vans, the majority of accidents in which vehicles collided with pedestrians occurred where speed limits are 30 mph or

less regardless of vehicle powertrain type (93.4% for E/HE vehicles and 91.4% for ICE vehicles). It was not possible to determine the speed of the vehicles at the time of the accident and as such it is unknown whether hybrid vehicles were operating in full electric mode at the time of the accident. Furthermore, it cannot therefore be determined whether a lack of noise from E/HE vehicles was a contributory factor in the accident.

The E/HE vehicle dataset was too small to allow a more detailed, meaningful assessment of the accident statistics in terms of parameters such as location (at or away from junctions and the availability of pedestrian crossing facilities) and vehicle manoeuvres.

6.2 Conclusions arising from the measurement of noise levels from E/HE and ICE vehicles

A sample group of 4 ICE vehicles and 4 E/HE vehicles have been used to conduct a series of measurements under different operating conditions (steady-speed pass-by, pull-away from rest, low-speed parking manoeuvres). The majority of the ICE vehicles were the latest models (registered since mid-2009). The results of the measurements showed that:

1. When travelling at low steady speeds (7-8 km/h), the E/HE vehicles were, on average, 1 dB(A) quieter than the ICE vehicles. It is noted that at these speeds, the vehicles were typically 3 dB(A) above the background noise level.

   An increase in level of 3 dB(A) will be detectable by an adult with normal hearing.

   Under faster steady-speed conditions (20 km/h and above) noise levels for the different vehicle types were, on average, similar as tyre/road noise becomes the dominant noise source.

2. At low steady speeds, one of the ICE vehicles was at least as quiet as the E/HE vehicles. This suggests that the potential risk to vision-impaired pedestrians from E/HE vehicles and quieter ICE vehicles could be similar.

3. When pulling away from stationary, overall noise levels for the different vehicle types were similar, however the results show that E/HE vehicles can, over the initial period of acceleration, be marginally quieter than their ICE counterparts but after the first 5m both vehicle types have broadly similar noise levels.

4. Other than peaks in the pass-by noise spectra related to exhaust noise, there does not appear to be any significant difference in the acoustic signature of ICE and E/HE vehicles, and as such nothing that suggests a pedestrian would clearly be able to differentiate between vehicle types.

6.3 Conclusions based on subjective assessments of E/HE and ICE vehicle noise

Ten vision-impaired participants took part in a laboratory-based subjective assessment of noise from the E/HE and ICE vehicles used in the track trials. The participants were not ‘representative of that part of the population suffering visual impairment’. Audio samples comprising vehicles performing different manoeuvres at different speeds were played to the vision-impaired participants, as if they were a pedestrian stood at the kerbside, in order to determine at what point the vehicle became audible. Each vehicle operated in isolation with no other traffic present.

Results were considered in terms of "risk exposure", based on the assumption that there will always be some element of risk, however small, for crossing pedestrians whenever traffic is present on the road. Risk exposure was deemed to be 'increased' if the presence of the vehicle was detected at a distance less than typical safe stopping distances or not detected at all. The results of the assessment showed that:

1. Although conclusions cannot be drawn that represent the situation at a national level, the subjective test results showed that in a semi-rural environment, the likelihood of increased risk exposure was 1.4 times greater for E/HE vehicles than for ICE vehicles. In urban conditions, the likelihood of increased risk exposure was 1.3 times greater for E/HE vehicles than for ICE vehicles (due to the reduced detectability of quieter ICE vehicles). The E/HE vehicles were far more difficult to detect than the ICE vehicles at the lowest steady speed and when pulling way from rest at the lowest speed.

Many of the vision-impaired participants had not previously encountered any electric vehicles other than milk floats and mobility scooters/wheelchairs.

6.4 Overall conclusions

Whilst the concerns of organisations associated with the vision-impaired are acknowledged, the results of the current research suggest that whilst there may be a potential risk to vision-impaired pedestrians from E/HE vehicles, particularly in urban environments, the scale of the problem is currently very small.

Audibility of these vehicles is only a problem at low speeds, where tyre/road noise is not the dominant noise source, and particularly in urban environments where background noise can potentially mask the noise of the vehicle. There are current model ICE vehicles on the market which are comparable in noise level to E/HE vehicles.

With further technological changes in engine design, particularly related to ICE vehicles, any future move to increase the audibility of E/HE vehicles at low speeds to address public concerns may also potentially have to take into account future model 'quiet' ICE vehicles.

Careful consideration will be required if 'added sound' is to be used to improve the audibility of quiet vehicles. This will need to take into account the environments under which the vehicle is being used, the low speeds and the differing levels of background noise that might have to be overcome to prevent masking the audibility of the vehicle. This therefore makes moves to impose minimum noise limits on vehicles challenging.

Improving public awareness of all quiet vehicles, both E/HE and ICE, in both pedestrians and drivers may be a first step in reducing perceived risk.

While an assessment of accident statistics has been performed in this study, quiet ICE vehicles were not distinguished from the rest of the ICE fleet. Therefore, a further investigation of the accident statistics, and future monitoring, is recommended which should consider quiet ICE vehicles as either an individual subset or in combination with E/HE vehicles. These statistics will not determine whether the potential reduced noise from quiet

ICE vehicles is a contributory factor, but they will provide a greater indication of the potential general risk from such vehicles.

In order to perform such a statistical analysis, it will be necessary to define a limit value under specified operating conditions below which any vehicle will be deemed to be ‘quiet’. It is recommended that the expertise of the UNECE-GRB (Working Party on Noise)[5] and work within ISO be used in determining a suitable classification for a quiet vehicle.

[5] GRB is a subsidiary body of the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29)

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Glossary of terms and abbreviations

BRRC	Belgian Road Research Centre
DfT	Department for Transport
DVLA	Driver Vehicle and Licensing Agency
E/HE	Electric/Hybrid Electric
GRB	UNECE Working Party on Noise
GVW	Gross Vehicle Weight
ICE	Internal Combustion Engine
JCMBPS	Joint Committee on Mobility of Blind and Partially Sighted People (UK)
KSI	Killed or Serious Injury
NHTSA	National Highway Traffic Safety Administration (USA)
OTS	On The Spot (DfT accident investigation project)
SDS	State Data System (USA)
SMA	Stone Mastic Asphalt
UNECE	United Nations Economic Commission for Europe
VRM	Vehicle Registration Mark
VSRC	Vehicle Safety Research Centre

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Appendix A Questions and responses from subjective audio trials

This section summarises the views, comments and feedback of the vision-impaired participants during the subjective audio trials and is structured as follows:

- Section B.1 summarises the questions and responses associated with the first part of the trial, i.e. the discussions to gain an understanding of their level of the visual impairment and their behaviour as a pedestrian
- Section B.2 summarises the comments associated with the third part of the trial, i.e. the audio trial where the vision-impaired participants listened to audio samples of different vehicles, both E/HE and ICE, performing different manoeuvres
- Section B.3 summarises the comments associated with the audio samples of the electric vehicle 'with added sound'

A.1 Questions posed to the vision-impaired participants

The following questions were posed to the vision-impaired participants as part of the discussion session.

1. Have you had visual impairment all your life or is it something acquired later in life?
2. What, if any, residual vision do you currently have? Does this extend to shapes, colours?
3. Do you wear a hearing aid?
4. When crossing the road, what influences your choice of crossing location?
5. What do you consider are the most significant hazards to you when crossing the road?
6. How do you negotiate your way around or through a car park?
7. What audio cues do you use when crossing the road?
    a) What do you listen for to tell you when it is safe to cross?
8. a) What visual cues do you use when crossing the road?
    b) What do you look for to tell you when it is safe to cross?
    c) Are audio or visual cues more important to you when crossing the road?
9. IF PARTICIPANT HAS NOT ALWAYS BEEN VISION-IMPAIRED: Does that influence your crossing behaviour now?
    a) If the audibility of quiet vehicles could be improved, what types of sound would you prefer (engine noise, reversing alarm type signals, natural sounds)?
    b) If non-audible technologies were to be developed in the future which would alert you to the presence of quiet vehicles, would these be useful (e.g. vibrations through a white stick or mobile phone, etc)?

The following tables summarise the participant responses to these questions.

Vision impaired participant	Question 1: Have you had visual impairment all your life or is it something acquired later in life?
1	Yes, since birth
2	Worn glasses from when started school, failed Army medical when 19 because of poor eyesight. Only has one eye
3	All my life
4	Yes
5	Yes
6	Yes
7	Yes, lost sight around age of 5
8	Had vision until mid-teens
9	Acquired visual loss at 25, about 40 years ago
10	Most of my life, deteriorated over time. Got worse in 1990 after a cataract operation, and worse after another deterioration in 1999

Vision impaired participant	Question 2: What, if any, residual vision do you currently have? Does this extend to shapes, colours, etc.?
1	Very little, just in left eye, just light and dark. Nothing in right eye. Some shapes but only if nearby. Very misty. It's the cornea that is the problem
2	Registered as severely visually impaired / blind. [Can't see faces, can see shapes, depends a lot on light conditions. With one eye, have no perception of depth. Can see some dark and light, and some colours.]
3	If I look at the sun I might be able to see some light. Can't see any shapes
4	None
5	Not now. Did up to 15-20 years ago. Can see light and dark and some shapes within a couple of feet
6	None
7	Can see shadows periodically, can see light and darkness
8	Nil by the time 17/18. no shapes
9	Had residual vision until 30, but now no light perception, no shapes
10	Can only see light and dark, can see an outline and bright colours

Vision impaired participant	Question 3: Do you wear a hearing aid?
1	No
2	No
3	No

Vision impaired participant	Question 3: Do you wear a hearing aid?
4	No
5	No
6	No
7	No
8	Hearing aid in both ears
9	No
10	No

Vision impaired participant	Question 4: When crossing the road, what influences your choice of crossing location?
1	Where there is a proper pedestrian crossing, or at least a zebra crossing.
2	Try to choose somewhere where it's free of obstructions and with the central refuges. [Don't cross unfamiliar roads on my own]. [Crossing sequence:] I always carry my white stick, and would have that in front of me, extended, and stand back from the pavement and stand and listen. I'd look and hopefully cross the road successfully at the end when I'd got confidence
3	[If crossing a road that is busy] I would want to go to a regular crossing point, maybe traffic lights with a pedestrian control, or maybe a point that is a busy crossing, so that I could cross with, or at the same time as, other people. If it's not a busy road, I would prefer to find somewhere which I know is a visible point, because fast moving cars can be worse than heavy slow traffic. If it's a side street and I can be pretty confident I can hear all the sounds, I might cross at any point. The older you get the more careful you become.
4	If there was tactile paving that would help me to work out where to cross the road. Also I would assess the traffic; Pelican crossings are quite handy for that. Otherwise I wait until I am absolutely sure that there is nothing coming and nothing likely to come, and then cross the road. I'm usually quite happy to wait 5 minutes if takes that long to be absolutely sure that it's safe to cross, and if I hear a vehicle idling I will not cross unless they've told me I can cross. I wouldn't chance it just in case they were about to move.
5	[If there are controlled crossings would make a significant effort to use those, even if walking a 100 yards to use a controlled crossing over a busy road]. Tactile paving, which aren't associated with controlled crossings [but] usually indicate a safer place to cross and can indicate an island refuge across a busy road. Places where you think traffic is going to slow because of traffic calming measures. In an unfamiliar environment it's just a matter of judgement where you can hear traffic & there's no background noise. To move away from areas where other noise might mask the sound of traffic.
6	The presence of pelican crossings, particularly when they have rotating cones on the underside to indicate when it is time to cross. [Won't use regular traffic lights to cross, prefers to make a longer journey, to feel safer].
7	If it is a busy road, prefer to cross at an official crossing point, such as pelican crossing. If it is relatively quiet, like a side street, I will cross wherever is most convenient for where I'm going.

Vision impaired participant	Question 4: When crossing the road, what influences your choice of crossing location?
7	If I'm walking down a busy road and have to cross lots of side streets, depending on how busy they are, I might indent quite a distance in order to diminish the amount of noise off the main road, but usually I just cross where the side street intersects with the busy road
8	Where there are pedestrian crossings I use them, or cross at corners or side streets. [Would go to the edge of the kerb, listen for the traffic and judge the moment it is safe to cross].
9	I will cross at a junction where I know that if traffic is coming fast on my right shoulder I know it's not going to turn left in front of me so I cross. If I know there's a light control or a zebra crossing not too far away I'll use that. Other than that I will stand on the kerb, listen until I think it's safe to cross
10	It would have to be a tactile indent. I would listen to hear the traffic, and if it was safe to go I would cross but I would be listening as I cross. There might be a little bit of vision but mostly I'm listening. If there was no tactile I would look for lights, or ask a sighted peer.

Vision impaired participant	Question 5: What do you consider are the most significant hazards to you when crossing the road?
1	Biggest hazard is the traffic which is why I use a proper designated crossing.
2	Cyclists - totally unaware of people. They go through lights and crossing, and don't conform to the highway road. Parked vehicles - blocking the sight line.
3	Vehicles that don't want to stop, situations where traffic will stop and block the crossing because the crossing point is a little before a traffic intersection, so the traffic will back up and obstruct pedestrian crossing. Or the traffic will roll on because they've got their eyes on the big issue of the traffic intersection and don't realise that they are slowly rolling over the pedestrian point. There are also the vehicles that don't make much noise, and bicycles can be a problem.
4	Drivers that aren't looking where they are going. I've had a couple of near misses where they've driven in front of me even though it's okay for me to cross the road. Also cars that are parked in a dodgy place on the crossing so that I have to navigate round the car.
5	Bicycles, because you can't hear them coming. If you have a clear audio path for traffic you should always be able to spot oncoming traffic. You do need a refuge when you are crossing a two-lanes in each direction.
6	A hazard might be a quiet vehicle appearing out of nowhere. There aren't any specific worries if I use the pelican crossings. If I have to cross the road where there is nothing to indicate the colour of lights I might be concerned if I make a misjudgement.
7	Vehicles. Particularly at junctions where you have lots of overlapping traffic sounds it can be hard to tell where all the traffic is coming from. Junctions where the corners are heavily curved, it can be difficult to walk across the road. You can be directed diagonally to the middle of the junction.
8	Used to have guide dogs but not for the past two years. Made me more anxious [to cross the road now]. Ambient noise - building work, lawnmowers, aeroplanes. It makes it impossible to hear if there is any traffic. Then it makes you dependent on someone else.
9	Cycles, quiet vehicles, occasionally it is windy and difficult to hear. There are some conditions if it is really windy, raining very heavily, sounds are distorted, the tyre noise on the wet roads, there are some conditions when it is more difficult than others

Vision impaired participant	Question 5: What do you consider are the most significant hazards to you when crossing the road?
10	Someone parked on the pavement when they shouldn't be. Parking on a crossing would be hazardous, because I would end up walking into it.

Vision impaired participant	Question 6: How do you negotiate your way around or through a car park?
1	The car park I use I know because I use it every week, and it has a path across the middle of it. Where there are internal crossings within it, there are "bubble bricks". If it's a car park I didn't know, I would probably have assistance anyway
2	Walk closely along the row of parked cars. [Wouldn't walk down the middle]. Would always be with somebody
3	I don't like car parks. I try to avoid them. I would use my stick, and use my knowledge, for example, if I discover there is a pavement around the periphery of the car park, I would prefer to use that. A car park is a problem area because it is likely to have more than one row of cars, and it looks logical to a car driver, but it is a very open space if half of the cars have gone. [Hazards] the cars because they can have bits sticking out, the open space which doesn't give you much clue as to where you should go, the possibility of signposts
4	I am very reliant on [my guide dog] to get me around, which paths are safe to take, otherwise I'd probably go with someone sighted to be on the safe side
5	You have to get an idea by touch how the cars are orientated, then keep to a right angle to make a satisfactory crossing of the car park. It's not particularly dangerous, the main problem is getting lost because of the lack of structure that is not apparent, because you have lost your kerbs. If there are no cars in it can be a bit of a wilderness. [if cars are manoeuvring slowly?] You are at risk of being backed into, but if the car is going forward you are not usually at risk. You can usually use the car drivers help to get you across because they want you out of the way as quickly as possible. Sometimes it's just the lack of people that inhibits your mobility. When you have people to ask, you use that information, or their direct help, to get across difficult areas.
6	I never usually find myself in a car park.
7	Comments missing
8	I don't go to places like that.
9	Comments missing
10	Always had somebody with me.

Vision impaired participant	Question 7: What audio cues do you use when crossing the road? What do you listen for to tell you when it is safe to cross?
1	If it's a pelican crossing with bleeps, that's what I would use. If it's a zebra crossing I would rely on hearing the traffic stopped, which it should do, but doesn't always do
2	[If a pedestrian crossing] I like to hear chimes, although sometimes they are not that clear because of other noise. A lot of crossings don't have them. Listening for vehicles and other street noises.

Vision impaired participant	Question 7: What audio cues do you use when crossing the road? What do you listen for to tell you when it is safe to cross?
3	Number one: whether there is some sort of bleeping audible. If that is not the case, I would work on the basis of whether the cars have stopped.
4	Traffic noise, and can a pelican crossing to work out when to cross the road.
5	Just the sound of oncoming traffic - a combination of car engine noise and tyre noise
6	If the crossing has the bleepers, I listen for those. If I know the traffic pattern, I will listen for that. I will use rotating cones if available in preference to audio feedback. At my local Asda store, if I can hear traffic flowing on one arm of the roundabout, I know it's my turn to cross.
7	I've got good hearing, so I can hear a car from quite a distance. If it's a good distance away I can cross before it reaches me.
8	Comments missing
9	Engine noise, tyre noise, audible signals. Listening for car noise, judging distances, whether I've got time to cross, engine pitch to see if they've got their foot on the accelerator or whether they've taken their foot off, and they've spotted me. Just driver awareness.
10	Would listen out for a car that's coming. The cars that come along are quite loud.

Vision impaired participant	Question 8a (only asked if participant has residual vision): What visual cues are used when crossing the road?
1	If it's dark and not a wide crossing I can sometimes see the red and green man, but not any other times. Also, if I press the button on the yellow box, and if it is dark, I can tell when the "wait" sign is on, if I am close by
2	Very little vision used.
3	[None]
4	[None]
5	[None]
6	[None]
7	Visual is non-existent
8	[None]
9	[None]
10	[None]

Vision impaired participant	Question 8b: What do you look for to tell you when it’s safe to cross?
1	[In an unfamiliar area] I would have assistance for the whole journey. If I was on own, would look for tactile paving to see where the crossing was.
2	Engine sounds. [when is it safe to cross?] if it's quiet. I'd be checking continuously left and right that vehicles had stopped if it's a pedestrian crossing. Extreme vigilance really, reassuring myself that I had got it right.

Vision impaired participant	Question 8b: What do you look for to tell you when it’s safe to cross?
3	If you are crossing a two way street, or a street with two lanes in each direction. I would start to cross if I felt fairly certain that the traffic coming toward me from my right had come to a standstill, or if a substantial vehicle like a bus had come to a standstill to let me go. I would go on the basis that I could got halfway, and I would show my stick prominently. I would get to halfway and I would try and repeat the process. I try to feel certain that I am shielded by vehicles that have stopped for me. When crossing a quiet side street, the worse thing for me is when someone stops, running their motor and is waiting for me to cross. I have had experiences where other vehicles have come behind the first one, overtaken, and I could be trapped. I would rather get off the road and wait until it's quiet.
4	I have to make the decision ultimately. [The guide dog] won't let me cross if she thinks it's not safe. I am very reliant on my hearing to help me decide when to cross the road.
5	Get to the edge of the crossing, give the dog the instruction that he should be paying attention, check that you can't hear anything coming from the right, then check can't hear anything from the left, give the dog the instruction to cross, tell the dog to watch because you may have to stop halfway. Encourage the dog to go at a proper pace, right across the road.
6	I would cross the road and use pelican crossings where they are available. Generally wholly cross the road when it is the indication that it is my turn to do so.
7	Whether there are any cars coming. I'll stand at the kerbside and listen to hear if there's any traffic coming. If there is, I make a decision based on is it coming towards me, is it going away from me, is it far enough away for me to still cross and get safely to the other side of the road before it reaches me.
8	I decide that I can get across in a single movement, when there is a side street without having to stop in the middle of the road to listen again. When it’s a main road you have to cross to an island, go round then at the other side you have to wait again. I always use my white cane, holding it up in front of me so the driver can see it as a last safety measure. I wouldn't want to cross the road just hoping for the best.
9	Depends on the volume of traffic. If it was really busy I would probably get sighted help. I would wait on the kerb and assess a safe time to cross. [Does the guide dog help with decision?] You can't rely on a dog on a busy road,
10	By listening to hear that there's no cars coming along at a fast speed. Audible sound on the traffic lights, and if there's no audible sound I have to use the cone under the box.

Vision impaired participant	Question 8c: Are audio or visual cues more important to you when crossing the road?
1	Audio
2	Audio cues. Very little vision used
3	Audio
4	Comments missing
5	Comments missing
6	Comments missing
7	Audio more important. Visual is non-existent

Vision impaired participant	Question 8c: Are audio or visual cues more important to you when crossing the road?
8	Audio
9	Audio
10	Audio

Vision impaired participant	Question 9 (Only asked if the participant has not always been vision-impaired): If you have not been vision-impaired all your life, does that influence your crossing behaviour now?
1	N/A
2	[Although had only one eye] until 6 years ago was working full time and driving 20k miles a year, day, night, fog, snow. Only been registered blind in last 6 years. [Initially was very uncertain of going out or doing anything]. I've grown more confident in crossing roads now (although wife is worried for me crossing the road)
3	N/A
4	N/A
5	N/A
6	N/A
7	N/A
8	N/A
9	When I first lost my sight I wouldn't cross unless I couldn't hear a car. You learn to judge speed and distances, and traffic.
10	N/A

Vision impaired participant	Question 10: If the audibility of quiet vehicles could be improved, what types of sound would you prefer (engine noise, reversing alarm type signals, natural sounds, etc.)?
1	Having never been in that situation, I think I would probably prefer it to be a similar sound to what cars make already
2	The sounds they'd make as proper vehicles, petrol or diesel vehicles. Got quite good hearing
3	I just don't know. I think this is a real problem. I don't know what sound I would want to hear. You could pick almost any sound and you would get people saying it was a problem.
4	As long it was clear, and it was obvious that it was a hybrid vehicle of some sort, then anything would be fine, as long as you could hear it and could work out what it was. Some kind of engine noise that that was loud enough that you could detect it easily. [Have you come across electric vehicles?] Ridden in one once, I've never come across one when I was crossing the road, but I know that they are completely silent when they are waiting. Would prefer some sort of engine noise.
5	Difficult to say, by taking the engine noise off not sure what's left. Normally it's engine noise plus tyre. Probably a low hum. Don't want it to be a penetrating because that would just annoy people. Something that just adds a low murmur [in terms of frequency]. The problem with high frequency is that it doesn't bend around other objects as easily as low frequency.

Vision impaired participant	Question 10: If the audibility of quiet vehicles could be improved, what types of sound would you prefer (engine noise, reversing alarm type signals, natural sounds, etc.)?
6	I would want them to sound as near as possible to what ordinary vehicles sound like
7	Something that's going to carry, and a sound that's not going to be confusable with anything else. As well as not going to be confusing as to which direction it's coming in. Something that's not going to echo, to not sound like it's coming from the right rather than the left.
7	I suppose I would just like an engine sound like the old-fashioned petrol engines that are easy enough to pick up on.
8	Low-pitched and audible, presumably the car would be equipped with a signal that the driver can give. [Prefer a car engine sound?] Yes. Used to have trolley buses and that was difficult because they were really silent.
9	You'd want something that mimics petrol or diesel engine noise. It wouldn't need to be a constant noise. It would need to be a high-pitch... imitating a traditional petrol or diesel engine, so the faster it was going the higher it would be revving
10	Only ever heard one - an electric wheelchair. It was quite a loud sound. Whereas an electric car would probably be a lot less. I haven't heard one. Wouldn't want a reversing sound. Probably a natural sound.

Vision impaired participant	Question 11: If non-audible technologies were to be developed in the future which would alert you to the presence of quiet vehicles, would these be useful (e.g. vibrations through a white stick or mobile phone, etc)?
1	[e.g. vibrating stick] Yes it would be useful but I think I would still prefer the actual noise
2	[Prompt: Useful?] Very. Most people have a stick. If it had a chip implanted in it that gave off a bleep, and the vehicles had something on them that gave that bleep, that would be brilliant. Or on a wristband if you don't want to carry a white stick. I don't use mobile phones. Most visually impaired people don't use mobile phones.
3	It might be good to have a device that could give a personal bleep when interrogated, like "Is it safe to cross?" "Can I start crossing?" Maybe something that could be found to be foolproof, that works like radar? [Prompt: Vibration through white stick?] You wouldn't force everybody to have the same feedback. Deafblind people usually don't have the benefit to be able to hear the bleeps. As long as it can be interrogated in an easy way. [Prompt: What about non-audible?] I would prefer audible things. You might have something in your hands.
4	[Prompt: Vibrations through a white stick?] Possibly. I would prefer a sound really
5	Another survey I did recently about interrogating environments where information could come back through some device. The idea that we might be carrying such electronics on our persons is coming, and I would welcome that very much.
6	[Prompt: Vibrations through a white stick?] I would imagine that they might be
7	Audible would be best, but if you could connect to a Braille display to indicate when a vehicle was coming. One project I'm hoping to be involved with is with satellite navigation systems. Using vibrating feedback, possibly the cane or the Guide dogs handle
8	Certainly, may even be preferable, as long as it's safe

Vision impaired participant	Question 11: If non-audible technologies were to be developed in the future which would alert you to the presence of quiet vehicles, would these be useful (e.g. vibrations through a white stick or mobile phone, etc)?
9	[Ability to receive vibrations through the white stick] Can't envisage that being very reliable and giving me sufficient information, unless it was something that vibrated at a higher pitch the closer it got. I find it difficult to imagine something that would give me anything equivalent to an auditory signal
10	That might be useful. I've always thought there should be something vibrating at the end of a cane. That would be a good one.

A.2 Feedback and comments related to the audio trial

Vision impaired participant	General feedback and comments
1	The audio sounded like there was a bit of a motorway in the distance, which I found a bit strange. In one of the samples I thought I heard a bike rather than a car. I would not cross the road if could hear a vehicle.
2	Comments missing…
3	It seemed that the listener was placed in a broader landscape (than you described), being positioned at the edge of a quiet, non-main road but with a busier road in background, further away. Perhaps positioned at an adjacent road behind some trees. Sometimes I could hear something but had to wait to decide whether it was on the busier road or on my road. The birdsong seemed isolated - maybe there were two different settings going on.
4	In the urban setting (second group) there were some very quiet vehicles, I would not surprised if I missed some. I may have heard something after it passed. A bike may be like that or a car with its motor not engaged, a lot of cars can sound very bike-like. I think that I missed something – I didn’t tap as didn’t feel that had facts – I heard something approaching but couldn't have sworn that I observed it. The majority of vehicles run fairly smoothly, I’m not sure that I’ve experienced many electric vehicles other than milk floats. Most of the time I’m saying that the vehicles are petrol unless sounds like a space ship. In some ways the audio seems realistic, in other ways it doesn’t. The sense of movement is realistic, hearing the vehicles in the distance. The further away the less directionality/less chance there is to determine movement. At distance I suspect that sound is not too faithful.
5	It was perhaps a bit disturbing in the last setting (urban traffic lights) as I think that the vehicles were quite close before I detected them. In a more distracted environment with people talking etc. (highly pedestrianised situations), it would be more complicated as traffic is two ways. I might walk into side streets as there is less through traffic. Main roads are solid traffic (where I live) and there are lots of people around. I would not cross on main roads by myself except at traffic lights or pedestrian crossings as I wouldn't be able to judge the traffic to cross the street. I might cross the main road late at night or early in the morning. 10 years ago might have (crossed the road in daytime), but now I only cross at pedestrian crossings as the environment is too complex. I might be happy to cross a side street at any point as long as can hear nothing coming anywhere close and I can display my stick so drivers can slow down or beep their horn.
6	I thought I heard something coming that never came (commenting on background traffic noise). In the urban car park situation I couldn't tell where the vehicles were moving or where they were. Also, in the final urban audio sample I couldn't tell the vehicles was there until it was actually on top of me.

Vision impaired participant	General feedback and comments
7	At the end of the 2nd and 3rd audio samples (of the first group) I could hear a car approaching but it never came (detected background fade-out). I picked up tyre noise rather than engine noise. In the last audio clip (of the first group), I'm sure there was an electric vehicle that sneaked through that I didn't pick up. I think that some of the vehicles that I said were petrol were actually electric. In the real world, I quite often hear tyre noise more than engine noise. Petrol engines are generally quiet these days; it is less worrying than I thought it might be. I would cross a road even if I heard that as the traffic is coming so slowly. Sometimes I picked the sound up quite early on - I would still cross, although that depends on having the knowledge that it is not a difficult road. I found the audio where the children were chatting a bit disconcerting but generally not too bad. Traffic travelling at speed generates enough tyre noise to detect so whether it is petrol or electric isn't important. When cars are moving fairly slowly, there is less tyre noise so the type of vehicle becomes more significant (i.e. traffic lights scenarios), a petrol vehicle would make more noise than an electric vehicle. The engine noise is the only noise louder than the tyre noise. in some sense the slower cars were more hazardous than the faster ones, with the particular street scene a good corridor to pick it up, nothing from left so able to concentrate as if a one way street so were able (to detect), cars moving generally to order of 20 mph
8	No specific comments stated.
9	I think I got knocked down in one of the clips! Tapped early on 3rd one back (of the first set) but didn't hear it go past. There was a slight change in sound quality and sometimes I thought it was the sound of the car coming in the distance, but then the car appeared 5 seconds later. This is quite distracting as I can pick up where one bit ends and another starts. All of the vehicles seem to be coming in at the same point. The audio is freaky as it feels like the car is right in front of you and you could touch it as it went by, which is exactly how it would be (for a pedestrian standing at the kerb). I'm not sure if I've heard any accelerations – when a vehicle is passing there would be a solid note but accelerations are different. I'm not sure that I've heard this. I think I may be detecting electric vehicles later than petrol ones. Sometimes it is harder (for me) to tell difference between petrol and electric at slow speeds. I find it easier to tell (them apart) when they're going faster. Slow-moving petrol cars appear to be quieter. The trial would be more realistic if had cars from both sides.
10	There was a general noise of traffic which sounded distant without anything actually passing in front of me. There were also some intermittent high frequency noises that I couldn't identify. All of the vehicles came from the right which made the task easier. It is important that live tests are conducted in the future. I live near a main road and sometimes it is difficult to tell if I can hear something coming whilst crossing the side street.

A.3 Feedback and comment related to the audio samples of the electric vehicle 'with added sound'

The following questions were posed to the participants following playback of the audio samples:

1. What are your general perceptions of the vehicle sounds that you have just listened to and your general comments?
2. What improvements do you think could be made to the 'added sounds' to improve them?
3. Having heard this example, what type of 'added sound' would you prefer to be used on electric vehicles to improve their audibility?

The following tables summarise the participant responses to these questions.

Vision impaired participant	Question 1: What are your general perceptions of the vehicle sounds that you have just listened to and your general comments?
1	The acceleration/start-up sound was recognisable. The sound in general wasn't bad and quite reasonable. Sounded like a milk float so I would recognise it as a vehicle.
2	This vehicle sounded completely different to the other electric vehicles in the trial. The pass-by noise was not recognisable as a vehicle – it sounded like an electrical drill. The acceleration noise sound more like a vehicle but not like the others. Some visually impaired people don't have good hearing and may not hear the high pitched noise. It needs to be distinguishable from any other street noise.
3	Not a pleasant sound – it has whining characteristics and would annoy people. It might alert you to the presence of a vehicle in a similar way to a police siren but I'm not sure it is the answer as it is an artificial sound. It has ringing characteristics that have a jamming effect. The whining sound makes it hard to locate the vehicle even though it is heard. Sounds similar to a milk float. If I got used to the sound then it would probably be ok. If this vehicle is shielded by other vehicles it won't tell you anything more than that it is there whereas a brushing movement would also indicate its speed. A lot of petrol vehicles are quiet especially if there is high background noise e.g. a car in front of a bus.
4	The acceleration noise was better than the pass-by noise. A vehicle with that pass-by noise could be missed easily.
5	The pass-by and acceleration samples both contained a high frequency sound and it is not necessary for them to be that high. I don't think that added sound it necessary. Modern cars are equipped with sat-nav/GPS and wouldn't need added sound on a motorway although in residential areas there might be a need to (link vehicle location to determine whether to add the sound). Tyre noise detected more than engine noise at faster speed.
6	The added noise made the vehicle more detectable and a sound like this would be helpful. As it was different to the ambient sound, I could tell that it had a definite musical frequency, which made it stand out. I would probably associate the noise with a vehicle.
7	I like the sound; it makes it easy to detect the vehicle because of the high frequencies. The pitch goes higher when it accelerates, the sound carries and I can tell which direction it is coming from. This car is easier to detect than other electric vehicles. The sound is good as it is continuous and not something that is heard frequently so it would not be confused with something else. I think it is a sound that I'd have to get used to in order to associate it with a vehicle. The high frequency characteristics of the sound may not alert people with hearing impairments.
8	It is high pitched, a definite whining sound and has to be right in front of me before I can hear it. It is higher pitched than the other vehicles. I only heard one of them (acceleration?). I would associate that noise with a vehicle.
9	The sound of this vehicle is better than some existing electric vehicles. I would detect the presence of this vehicle but not in London traffic or windy conditions. I don't think it would he heard in heavy traffic.
10	The vehicle was louder when it was accelerating and had a more distinctive sound. The pass-by sound was not as good as it was too quiet. I would be worried about being caught out at a crossing island whilst trying to decide if it is a car or not.

Vision impaired participant	Question 2: What improvements do you think could be made to the 'added sounds' to improve them?
1	I would prefer it to sound like a petrol engine.
2	I would prefer a sound that can't be confused with a drill or any other electrical whirring noise. I would prefer it to sound like a noisy vehicle or something completely new that can be associated with a vehicle. It has got to be loud, not subtle and potentially offend other people!
3	I would prefer a mid-frequency sound that doesn't resonate e.g. a brushing sound with a circular/turning movement such that the striking action is related to the speed of the vehicle.
4	No improvements stated.
5	Make it position dependent (to turn the added sound on in residential/urban areas) or speed dependent to improve the audibility at low speeds. The added sound is not necessary at high speeds as tyre noise is dominant.
6	I think that this sound is okay.
7	No improvements stated.
8	No improvements stated.
9	The sound needs to give a better indication of speed of travel. It has a constant pitch which doesn't give any indication of speed.
10	The sound is okay and can be improved by being louder.

Vision impaired participant	Question 3: Having heard this example, what type of 'added sound' would you prefer to be used on electric vehicles to improve their audibility?
1	I would prefer it to sound like a petrol engine.
2	I would prefer a sound that can't be confused with a drill or any other electrical whirring noise. I would prefer it to sound like a noisy vehicle or something completely new that can be associated with a vehicle. It has got to be loud, not subtle and potentially offend other people!
3	I would prefer a mid-frequency sound that doesn't resonate e.g. a brushing sound with a circular/turning movement such that the striking action is related to the speed of the vehicle.
4	No preference stated.
5	No preference stated.
6	Not sure if a different sound is preferred.
7	Ideally, a car engine noise would be preferred.
8	I would prefer a lower pitched noise. It needs to be loud enough for me to hear it, whether it is petrol or electric.
9	I would prefer something that simulated a traditional engine.
10	I would prefer the sound to be louder.

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Appendix B Subjective trial audio sequence descriptions

The tables presented in this Appendix summarise the conditions, vehicles and manoeuvres used in each of the audio sequences during Part 3 of the subjective trial.

Scenario ID number:	**1A**		
Scenario description:	Traffic lights/junction	**Vehicle categories**:	ICE vehicles only
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-03: 0.5ms^{-2} pull-away from rest ⇒ ICE-03: 20 km/h pass-by ⇒ ICE-01: 0.5 ms^{-2} pull-away from rest ⇒ ICE-04: 30 km/h pass-by; ICE-02: 50 km/h pass-by		

Scenario ID number:	**1B**		
Scenario description:	Traffic lights/junction	**Vehicle categories**:	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-03: 1.0ms^{-2} pull-away from rest ⇒ E/HE-01: 0.1ms^{-2} pull-away from rest ⇒ E/HE-04: 50 km/h pass-by ⇒ ICE-01: 30 km/h pass-by ⇒ E/HE-03: 1.0ms^{-2} ⇒ ICE-03: 1.0ms^{-2} pull-away from rest ⇒ ICE-01 20 km/h pass-by		

Scenario ID number:	**1C**		
Scenario description:	Traffic lights/junction	**Vehicle categories**:	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-01: 20 km/h ⇒ E/HE-02: 0.5ms^{-2} pull-away from rest ⇒ E/HE-01: 1.0 ms^{-2} ⇒ ICE-03: 20 km/h pass-by ⇒ ICE-02: 30 km/h pass-by ⇒ E/HE-04: 0.5ms^{-2} pull-away from rest ⇒ ICE-04: 50 km/h pass-by		

Scenario ID number:	**1D**		
Scenario description:	Traffic lights/junction	**Vehicle categories**:	E/HE and ICE vehicles
Background environment:	'Urban'		
Vehicle configuration:	ICE-02: 0.5ms^{-2} pull-away from rest ⇒ ICE-03: 30 km/h pass-by ⇒ E/HE-01: 30 km/h pass-by ⇒ ICE-01: 1.0ms^{-2} pull-away from rest ⇒ E/HE-04: 0.5ms^{-2} pull-away from rest ⇒ ICE-01: 20 km/h pass-by ⇒ E/HE-03: 0.5 ms^{-2} pull-away from rest ⇒ ICE-03: 1.0ms^{-2} pull-away from rest ⇒ ICE-04: 50 km/h pass-by		

Scenario ID number:	**2A**		
Scenario description:	Car park	**Vehicle categories**:	ICE vehicles only
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-01: 5 km/h pass-by ⇒ ICE-01: Forwards out of parking space ⇒ ICE-02: 5 km/h pass-by		

Scenario ID number:	2B		
Scenario description:	Car park	**Vehicle categories:**	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-03: Reverse out of parking space ⇒ ICE-03: 0.5ms^{-2} pull-away from rest ⇒ E/HE-01: 5 km/h pass-by ⇒ E/HE-02: Forwards out of parking space ⇒ ICE-01: 0.5ms^{-2} pull-away from rest		

Scenario ID number:	2C		
Scenario description:	Car park	**Vehicle categories:**	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-04: 5 km/h pass-by ⇒E/HE-04: Reverse out of parking space ⇒ E/HE-02: 5 km/h pass-by ⇒ ICE-03: 0.5ms^{-2} pull-away from rest ⇒ ICE-01: Reverse out of parking space		

Scenario ID number:	2D		
Scenario description:	Car park	**Vehicle categories:**	E/HE and ICE vehicles
Background environment:	'Urban'		
Vehicle configuration:	E/HE-02: Reverse out of parking space ⇒ E/HE-02: 0.5ms^{-2} pull-away from rest ⇒ ICE-01: 5 km/h pass-by ⇒ ICE-01: 5 km/h pass-by ⇒ ICE-03: Forwards out of parking space ⇒ E/HE-03: 5 km/h pass-by ⇒ E/HE-04: 5 km/h pass-by		

Scenario ID number:	3A		
Scenario description:	Road with 30 mph speed limit	**Vehicle categories:**	ICE vehicles only
Background environment:	'Semi-rural'		
Vehicle configuration:	ICE-03: 30 km/h pass-by ⇒ ICE-03: 50 km/h pass-by ⇒ ICE-04: 50 km/h pass-by ⇒ ICE-01: 20 km/h pass-by ⇒ ICE-02: 20 km/h pass-by		

Scenario ID number:	3B		
Scenario description:	Road with 30 mph speed limit	**Vehicle categories:**	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	E/HE-04: 50 km/h pass-by ⇒ ICE-04: 20 km/h pass-by ⇒ E/HE-01: 20 km/h pass-by ⇒ ICE-01: 30 km/h pass-by ⇒ ICE-01: 50 km/h pass-by ⇒ E/HE-02: 50 km/h pass-by		

Scenario ID number:	3C		
Scenario description:	Road with 30 mph speed limit	**Vehicle categories**:	E/HE and ICE vehicles
Background environment:	'Semi-rural'		
Vehicle configuration:	E/HE-03: 20 km/h pass-by ⇒ ICE-02 30 km/h pass-by ⇒E/HE-04: 20 km/h pass-by ⇒ E/HE-03: 50 km/h pass-by ⇒ ICE-01: 50 km/h pass-by ⇒ ICE-03: 50 km/h pass-by ⇒ ICE-04 30 km/h pass-by ⇒ E/HE-01: 20 km/h pass-by		

Scenario ID number:	3D		
Scenario description:	Road with 30 mph speed limit	**Vehicle categories**:	E/HE and ICE vehicles
Background environment:	'Urban'		
Vehicle configuration:	ICE-01: 30 km/h pass-by ⇒ ICE-01 30 km/h pass-by ⇒ E/HE-03: 50 km/h pass-by ⇒ ICE-03: 50 km/h pass-by ⇒ ICE-04: 30 km/h pass-by ⇒ E/HE-02: 20 km/h pass-by ⇒ E/HE-04: 50 km/h pass-by		

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Appendix C Determination of attenuation rates to for pass-by measurements

As noted in the description of the set-up for the steady-speed pass-by measurements, the standard position for vehicle noise measurements is not at the kerbside but at 7.5m from the centre of the running lane. This position is defined in ISO 11819-1:2001 (ISO, 2001), the standard which defines the procedures for the measurement of the influence of road surfaces on traffic noise. Measurements are less common on low-speed roads due to the presence of large reflecting obstacles such as walls and buildings in the vicinity of the measurement microphone.

However, to gain the greatest insight into the noise impact on vision-impaired pedestrians, it is considered more representative to assess vehicle pass-by noise levels at the kerbside position, i.e. 1.8m from the centreline of the nearest running lane, as adopted in the current study.

This study uses only a very limited range of vehicles. As such, for future analysis, it is considered beneficial to derive indicative attenuation rates in order to potentially allow kerbside noise levels to be estimated from those recorded during real roadside measurements at 7.5m. It is noted that these rates are based on measurements on a 14 mm stone mastic asphalt (SMA) surface and therefore may not be applicable to other surface types.

The difference between the noise levels recorded at microphones M1 and M2 (1.8m and 7.5m from the centre of the running lane respectively) for the vehicle pass-by tests varies depending on the vehicle type, the vehicle speed and the position of the vehicle.

At 7-8 km/h the differences are misleading since the vehicle noise is not significantly above the background. The differences experienced for the remaining speeds, in terms of attenuation per doubling of distance, are presented for each vehicle tested in Table C.1.

Table C.1: Approximate sound attenuation rate per doubling of source/receiver separation for steady-speed vehicle pass-bys

Vehicle	Steady-speed pass-by speed		
	20 km/h	30 km/h	50 km/h
ICE-01	3.2	3.3	3.5
ICE-02	4.5	4.7	5.1
ICE-03	3.6	4.2	5
ICE-04	4	4.2	4.5
E/HE-01	4	4.3	4.8
E/HE-02	4	4.2	4.5
E/HE-03	4	4.4	5
E/HE-04	3	3.2	3.5

Attenuation rates of 3 dB and 6 dB per doubling of distance would be expected for a line source and a point source respectively. The table indicates that at the lower speeds the attenuation rate is lower than at the higher speeds. This may be expected when considering that the vehicle takes longer to pass-by the microphone at lower speeds and will therefore act more like a line source in this instance than when passing by quickly at higher speed.