Synthesis title:

Electric Vehicle Safety

Category: Vehicles

Other Relevant Topics:

- Crash Mitigation and Collision Avoidance (Vehicles)
- Pedal Cyclists (Riders)
- Horse Riders (Riders)
- Adults (Pedestrians)
- Children (Pedestrians)
- Perceptions of Road Safety (Pedestrians)

Keywords:

Electric vehicle, Hybrid vehicle, Plug-in vehicle, Hydrogen fuel-cell vehicle, Safety, Hazards, Acoustic perception (noise)

About the Road Safety Observatory

The Road Safety Observatory aims to provide free and easy access to independent road safety research and information for anyone working in road safety and for members of the public. It provides summaries and reviews of research on a wide range of road safety issues, along with links to original road safety research reports.

The Road Safety Observatory was created as consultations with relevant parties uncovered a strong demand for easier access to road safety research and information in a format that can be understood by both the public and professionals. This is important for identifying the casualty reduction benefits of different interventions, covering engineering programmes on infrastructure and vehicles, educational material, enforcement and the development of new policy measures.

The Road Safety Observatory was designed and developed by an Independent Programme Board consisting of key road safety organisations, including:

- Department for Transport
- The Royal Society for the Prevention of Accidents (RoSPA)
- Road Safety GB
- Parliamentary Advisory Council for Transport Safety (PACTS)
- RoadSafe
- RAC Foundation

By bringing together many of the key road safety governmental and non-governmental organisations, the Observatory hopes to provide one coherent view of key road safety evidence.

The Observatory originally existed as a standalone website, but is now an information hub on the RoSPA website which we hope makes it easy for anyone to access comprehensive reviews of road safety topics.

All of the research reviews produced for the original Road Safety Observatory were submitted to an Evidence Review Panel (which was independent of the programme Board), which reviewed and approved all the research material before it was published to ensure that the Key Facts, Summaries and Research Findings truly reflected the messages in underlying research, including where there may have been contradictions. The Panel also ensured that the papers were free from bias and independent of Government policies or the policies of the individual organisations on the Programme Board.

The Programme Board is not liable for the content of these reviews. The reviews are intended to be free from bias and independent of Government policies and the policies of the individual organisations on the Programme Board. Therefore, they may not always represent the views of all the individual organisations that comprise the Programme Board.

Please be aware that the Road Safety Observatory is not currently being updated; the research and information you will read throughout this paper has not been updated since 2017. If you have any enquiries about the Road Safety Observatory or road safety in general, please contact **help@rospa.com** or call **0121 248 2000**.

How do I use this paper?

This paper consists of an extensive evidence review of key research and information around a key road safety topic. The paper is split into sections to make it easy to find the level of detail you require. The sections are as follows:

Key Facts	A small number of bullet points providing the key facts about the topic, extracted from the findings of the full research review.
Summary	A short discussion of the key aspects of the topic to be aware of, research findings from the review, and how any pertinent issues can be tackled.
Methodology	A description of how the review was put together, including the dates during which the research was compiled, the search terms used to find relevant research papers, and the selection criteria used.
Key Statistics	A range of the most important figures surrounding the topic.
Research Findings	A large number of summaries of key research findings, split into relevant subtopics.
References	A list of all the research reports on which the review has been based. It includes the title, author(s), date, methodology, objectives and key findings of each report, plus a hyperlink to the report itself on its external website.

The programme board would like to extend its warm thanks and appreciation to the many people who contributed to the development of the project, including the individuals and organisations who participated in the initial consultations in 2010.

Key facts

Crashworthiness

- The crashworthiness, also known has passive safety, of electric vehicles, differs from conventional vehicles because of the lack of an internal combustion engine (ICE) in (typically) the front compartment, the addition of battery packs and the structural modifications to the vehicle designed to cope with the associated increase in vehicle weight (Lassfolk et al., 2010).
- The market share of small electric vehicles relative to conventional ICE vehicles may increase further in future years; this could affect accident statistics, unless improvements in the “compatibility” of different vehicle types can be achieved (Visvikis, 2012).
- The United Nations (UN) has adopted the first international regulation (Regulation 100) on the safety of both fully electric and hybrid-electric vehicles to ensure that vehicles with a high-voltage electric power train are as safe as ICE vehicles (Visvikis, 2012).
- Crash tests with a Mitsubishi i-MiEV electric car by ANCAP and Euro NCAP revealed no problems with the battery or the electrical system (Paine).

Post-impact safety issues

- Electric propulsion technology carries some inherent risks which are unique to electric vehicles. Rechargeable energy storage systems (RESS) may be realised through the use of batteries, capacitors and electromechanical flywheels. Batteries, in particular, have raised a number of key safety concerns, including electrolyte leakage due to cell casing damage, chemical reaction to extreme temperature of fire, and electrical risks such as short circuit and electroshock (Visvikis et al., 2010).
- The lithium contained within lithium ion batteries is highly reactive and the electrolytes are highly flammable. Abuse tests have identified thermal runaway, electrolyte leaks, smoke, venting, fire and explosion as potential issues with lithium ion batteries. Internal and external protection mechanisms such as fuses and flame retardants have been incorporated into lithium ion batteries by manufacturers in an attempt to reduce these risks (Pesaran et al., 2009; Tjus, 2011).
- It may be noteworthy however that few serious incidents relating to lithium ion batteries have been reported despite extensive worldwide use over the last decade (Kalhammer et al., 2009; Pesaran et al., 2009).

- Hydrogen is colourless, odourless, burns with a blue flame undetectable in sunlight, disperses in air faster than natural gas and gasoline vapour, is more flammable in air and has a smaller molecular structure allowing it to more easily leak through materials. These factors are crucial considerations for the post-impact safety of hydrogen fuel-cell vehicles (Visvikis et al., 2010; Rigas and Amyotte, 2013).

Risks associated with low vehicle noise emission

- The National Highway Traffic Safety Administration (NHTSA) in the USA reported that HEVs were found to be *twice* as likely to be involved in a slow-moving accident with pedestrians as equivalent ICE vehicles. However, a separate study reported that the likelihood of being involved in a collision with a pedestrian was equal between EVs/HEVs and conventional ICE vehicles (NHTSA, 2009; Morgan et al., 2011).
- Any potential increased accident risk may be attributable to the lack of engine noise emitted from electric vehicles. Development of acoustic warning signals to replace the absence of engine noise may be warranted (Brand et al., 2012).
- Pedestrians with normal vision, blind pedestrians, and those with visual-impairments were able to detect the sound of an ICE vehicle from a distance of approximately 36m, but this reduced to 14m when detecting the sound of an EV. No information was provided on the speed of the moving vehicles, however (Altinsoy, 2013).
- In a study which showed 24 participants a video of a moving 2007 Toyota Prius coupled with one of six categories of sound: engine, horn, hum, siren, whistle and white noise, it was found that engine noise was most preferable as an auditory cue, followed by hum sounds and white noise (Wogalter et al., 2013).
- In a study with 15 visually-impaired participants, the addition of an approaching Vehicle Sound for Pedestrians (VSP) alert system to an HEV resulted in significantly faster and more reliable detection than an identical vehicle with no VSP system, and a conventional ICE vehicle. However there were no differences in the ability of participants to discriminate between the intended pathway of the vehicle suggesting that a VSP system may only enable faster detection of the presence of a vehicle (Kim et al., 2012).

Summary

- The emergence of electric vehicles has led to a number of unique safety concerns, including issues of crashworthiness (i.e. how the structural and weight differences of EVs compared with conventional internal combustion vehicles affect vehicle collision behaviour), post-impact vehicle safety (i.e. the challenges associated with high-voltage circuits, batteries or hydrogen fuel-cells following a vehicle collision) and low noise emission (i.e. the impact on vulnerable road users who rely on auditory cues to respond to approaching vehicles).

Crashworthiness

- Crashworthiness, also known as passive safety, of electric vehicles (EV) differs from conventional vehicles because of the lack of internal combustion engine (ICE) in (typically) the front compartment, the addition of battery packs and the structural modifications to the vehicle designed to cope with the associated increase in vehicle weight (Lassfolk et al., 2010)
- As a result, there are number of aspects of safety which are specific to EV crashworthiness. These include the structural behaviour of the vehicle (e.g. weight distribution, mass, and layout), mechanisms for protecting against high-voltage electrical circuits (to maintain integrity of the battery and electrical parts during a collision), mechanisms for protecting against chemical materials (e.g. to avoid electrolyte leakage and fumes into the passenger compartment), and mechanisms for protecting against fire (e.g. due to high-voltage cables, short circuits, or chemical reaction) (Widmann and Seibert, 2010).
- There are too few electric vehicles on the road to allow meaningful study of the risk of occupant injury compared with conventional ICE vehicles (Visvikis, 2012).
- If purely-electric vehicles penetrate the fleet in significant numbers, the market share of small cars may increase further relative to other vehicles. This may have an effect on casualty statistics, unless improvements in the “compatibility” of vehicles can be achieved (Visvikis, 2012).
- Electric vehicles have been submitted for consumer testing (Euro NCAP) and have demonstrated that they are capable of achieving a good score for occupant protection (Paine.).

Post-impact safety issues

- There are additional risks associated with electric and hybrid vehicle technologies which are relevant to post-impact safety concerns. These include, for example, battery safety and concerns over high-voltage electrical circuits in EVs and the implications of hydrogen leaks in hydrogen fuel-cell vehicles.

- The UN Regulation 100 specifies requirements for the safety of electric vehicles 'in-use' and the protection of users against electric shock. UN Regulations 94 (front impacts) and 95 (side impacts) have recently been amended to include requirements for post-impact electrical safety. But, many hazards associated with RESS are not covered by type-approval regulations; for example, there is currently no legislation relating to risks of extreme heat or fire on EVs (Visvikis et al., 2010).
- Electric propulsion in EVs is achieved via rechargeable energy storage systems (RESS) such as batteries, capacitors and electromechanical flywheels. The hazards associated with batteries have been given particular focus, which can include electrolyte spillage due to damage to cell casing, chemical reactions as a result of extreme temperature or fire, and electrical risks such as short circuit, over voltage, or electroshock (Visvikis et al., 2010).
- Lithium, used in lithium ion batteries for example, is highly reactive and the electrolytes are highly flammable. The safety of these batteries may be assessed via appropriate abuse tests (such as overvoltage, overdischarge, heating, arcing, crush, nail penetration and internal/external short). Results of such tests have identified a number of issues with lithium ion batteries including thermal runaway, electrolyte leaks, smoke, venting, fire and explosion (Pesaran et al., 2009; Tjus, 2011).
- It is important to be aware of the properties of hydrogen when dealing with hydrogen fuel-cell vehicles. Crucially, hydrogen gas is odourless and colourless meaning it cannot be detected by humans without the use of hydrogen sensors. The addition of odorants, like those introduced to natural gas, is not appropriate for use in vehicles because they can contaminate fuel cells. Hydrogen is also more buoyant, smaller in molecular structure and more flammable in air than gasoline vapour, meaning a greater risk of leakage through materials and a greater risk of fire when mixed with air (Visvikis et al., 2010).
- Because of the unique hazards associated with technologies present in alternative fuel vehicles, emergency responders must be able to easily distinguish EVs, HEVs, hydrogen fuel-cell vehicles and conventional ICE vehicles when attending incidents (Grant, 2010).

Risks associated with low vehicle noise emission

- Recent advances in 'green' alternative fuel technologies are increasing the prevalence of hybrid and fully-electric vehicles in today's marketplace. These technologies bring about reduced fuel consumption, reduced carbon dioxide emission and reduced vehicle noise emission. The latter has important implications for the safety of vulnerable road users, such as cyclists and pedestrians, particularly those who are visually-impaired, since the usual noise produced by an internal combustion engine is now absent. In low-speed environments particularly, aerodynamic and road-tyre sounds are negligible meaning road users have few available auditory cues to an approaching vehicle.

Collision with pedestrians even at speeds of 30 km/h can be serious, so the lack of noise emission may present a substantial risk (Voigt et al.).

- The detection of electric vehicles with low noise emission may be improved via the addition of synthetic sounds to act as a warning in the absence of real engine sounds. There is an important trade-off for the optimisation of such synthetic sounds; they must be optimal for health and social well-being of the neighbourhood whilst also conveying useful information about the driver’s intentions to vulnerable road users. This must include speed, acceleration and deceleration patterns, and braking (Chamard et al., 2012).
- Evidence suggests that the greatest risks to vulnerable road users occur when the EVs are travelling at low speeds, since the noise emitted from the friction between the tyres and the road surface, and the aerodynamic noise, are both minimal. Thus, at low-speeds, an EV may be near silent. It follows that these risks will be most prevalent in urban areas which enforce low speed limits (Cocron et al., 2010).
- However, there is mixed evidence that the number of accidents involving pedestrians is any different for electric vehicles and conventional ICE vehicles. The National Highway Traffic Safety Administration (NHTSA) in the USA reported that HEVs were found to be *twice* as likely to be involved in a slow-moving accident with pedestrians as equivalent ICE vehicles. However, in a review of vehicle accident statistics, the Transport Research Laboratory found that the likelihood of being involved in a collision with a pedestrian was comparable between EVs/HEVs and conventional ICE vehicles. It was also not possible to determine whether those accidents that did occur between pedestrians and EVs/HEVs were associated with the low noise emission of those vehicles (NHTSA, 2009; Morgan et al., 2011).
- Despite the lack of strong evidence that there is currently an increased risk to vulnerable road users posed by vehicles with low noise emission, the number of electric vehicles on the road may rise in the future which could increase the risk so investigation of measures designed to mitigate those risks are of value (Visvikis et al, 2010).
- There is good evidence that the addition of synthetic sounds is beneficial for the detectability of electric vehicles. The sound profile is an important consideration; ‘engine’ and ‘hum’ sounds appear to be preferred by visually-impaired pedestrians. For example, Nissan’s approaching Vehicle Sound for Pedestrians (VSP) system has been shown to be successful at increasing the detectability of a production Nissan electric vehicle (e.g. Goodes et al., 2008; Kim et al., 2012; Parizet et al., 2013; Wogalter et al., 2013).
- It is argued that the addition of synthetic sounds to electric vehicles may only be necessary until the majority of vehicles on the road have low noise emissions. After that turning point, a shift in public awareness may negate the need to add warning sounds to the vehicles (Voigt et al.).

Methodology

A detailed description of the methodology used to produce this review is provided in the Methodology section of the Observatory website at http://www.roadsafetyobservatory.com/Introduction/Methods .

This synthesis was compiled during November 2013 to January 2014. Searches were carried out on the pre-defined sources identified in this link. Search terms used to identify relevant papers included: electric vehicle, hybrid vehicle, plug-in vehicle, hydrogen fuel cell vehicle, safety, hazards, risks, crash, collision, accident, fire, explosion, acoustic perception (noise, low noise), visually-impaired, pedestrians, emergency (response, handling), legislation, standards, safety measures, short-circuit, isolation loss, electric shock, electromagnetic compatibility, functional safety, overcharge, over-discharge, thermal runaway, vibration, crashworthiness, battery integrity, battery retention, battery intrusion, submersion, electrolyte spillage, electrolyte containment, venting, hydrogen leakage, hydrogen permeation, hydrogen embrittlement.

Selection criteria

Research articles were scored on their relevance and quality. A rating of 'high', 'medium' and 'low' was given to each article under the following criteria.

For relevance

- 'High' refers to data on a metric clearly relevant to the topic under investigation
- 'Medium' refers to data on a metric that is probably relevant to the UK (e.g. UK legislation or standards for electric vehicles)
- 'Low' does not refer to data relevant to the topic under investigation

For quality

- 'High'= from a high-quality peer-reviewed publication, with clear and appropriate methods
- 'Medium'= from an academic source (e.g. book chapter, conference) but without peer-review, and/or possessing some methodological weakness (e.g. some possible confounding factors)
- 'Low'= from a more 'general' source (e.g. conference, trade paper) and/or clearly being methodologically weak or inappropriate (e.g. failing to address random variability by use of appropriate statistical techniques)

Forty-two pieces of research, statistical reports or policy documents have been included in this review.

The review covers research associated with electric vehicles, hybrid electric vehicles, and hydrogen fuel cell vehicles. The research was categorised under three headings: Crashworthiness, Post-impact safety issues, and EV noise emission.

Key statistics

Prevalence of electric vehicles in the general population

Electric vehicle registration figures are published every month by the Society of Motor Manufacturers and Traders (SMMT). The year-to-date figures for new car registrations at the end of 2013 were:

- 2,512 ‘pure electric’ plug-in EVs (up 100% from 2012)
- 1,072 ‘other electric’ plug-in EVs (up 8% from 2012)
- 26,017 petrol/electric HEVs (up 10% from 2012)
- 3,114 diesel/electric HEVs (up 140% from 2012)

Further information regarding Electric Vehicle registrations can be found at: http://www.smmt.co.uk/category/news-registration-evs-afvs/

Research findings

This section outlines a selection of research into electric vehicle safety. Articles have been categorised into issues of crashworthiness, post-impact vehicle safety and low noise emission.

Crashworthiness

- The crashworthiness, also known as passive safety, of an electric vehicle (EV), differs from conventional vehicles because of the lack of internal combustion engine (ICE) in (typcially) the front compartment, the addition of battery packs and the structural modifications to the vehicle designed to cope with the associated increase in vehicle weight.

  (Lassfolk et al., 2010)

- EV technologies must conform to unique safety performance requirements, such as electrical safety, cabin deformation, and the increase in mass associated with the replacement of a conventional fuel tank with a high-voltage battery. Nissan have developed an all-new platform for electric vehicles to achieve electrical safety and occupant protection. Specifically, Nissan have shown that:
  - Layout and body structure can offer protection of the high-voltage components.
  - High voltage shutdown may be achieved via an impact sensing system
  - Electric shock may be prevented through the use of fuses to mitigate against short circuits.
- Vehicle crash tests have been conducted to confirm protection of the battery, and cabin deformation of the EV during a frontal impact was shown to be the same as an ICE vehicle of similar size, despite the differences in mass. This was achieved by optimization of an efficient motor compartment structure and layout.

  (Uwai et al., 2011)

- There are number of aspects of safety which are specific to EV crashworthiness. These include the structural behaviour of the vehicle (e.g. weight distribution, mass, and layout), mechanisms for protecting against high-voltage electrical circuits (to maintain integrity of the battery and electrical parts during a collision), mechanisms for protecting against chemical materials (e.g. to avoid electrolyte leakage and fumes into the passenger compartment), and mechanisms for protecting against fire (e.g. due to high-voltage cables, short circuits, or chemical reaction).

  (Widmann and Seibert, 2010)

- If purely-electric vehicles penetrate the fleet in significant numbers, the market share of small cars may increase further relative to other vehicles. This may have an effect on casualty statistics, unless improvements in the “compatibility” of vehicles can be achieved, potentially through better self and partner protection requirements in the legislation and/or consumer crash tests.

(Visvikis, 2012)

- Vehicle safety issues may be classified under active safety, passive safety or post-accident safety. Electric vehicles share the same safety concerns as conventional ICE vehicles, as well some additional issues related to the on-board high-energy source (i.e. the battery) presenting risks including explosion, fire, electrolyte spillage, and electric shock. The main risk mitigation techniques for passive safety concerns involve the addition of automatic voltage-reduction and breaking systems, and protective devices for the battery. The main safety standard relating to electric vehicles is ISO 6469 which has three parts and has been adopted worldwide:
    - ISO 6469-1 (2009) documents requirements for the on-board rechargeable energy storage system.
    - ISO 6469-2 (2009) details operational safety measures and methods for protecting against failures and emergencies.
    - ISO 6469-3 (2001) is concerned with the protection of persons from electrical hazards, such as electroshock.

(Guibin and Yingnan, 2012)

- Daimler used a seven-stage safety concept for the worldwide first series-production vehicle with a Lithium-Ion battery. Similarly, an intrinsically safe packaging concept has been implemented in all Mercedes-Benz Hybrid- and Battery-Electric Vehicles. Its key elements are:
    - A ‘fool-proof’ strategy to cut-off the high-voltage electricity in accidents to prevent any electric shocks.
    - A concept of protection zones defines the accident-proof placement of all the safety relevant high-voltage components along with the highest possible structural safety.
    - Mechanical requirements for high-voltage components ensure the electric insulation and shock-proof protection.
    - An integrated safety concept shall prevent any critical damages to the high voltage battery in case of high crash loadings.

(Justen and Schöneburg)

- The voltages used in electric vehicles are potentially very dangerous but there are a range of safety features to ensure the safety of occupants and other persons.
    - UN Regulation 100: protection against direct contact, protection against indirect contact and isolation resistance.
    - Proposals to amend UN Regulation 94 (frontal impact) and UN Regulation 95 (side impact): performance criteria and measurement methods for protection against electric shock post-impact.

- Electric vehicles could present some potential functional safety hazards, particularly around the unintended operation of the powertrain by drivers.
    - UN Regulation 100 includes basic functional safety requirements that should reduce the likelihood (as far as possible) of unintentional vehicle movements.

(Visvikis, 2012)

- There are some limitations with applying current safety tests to EV technologies. For example, the KMVSS fire resistance test needs revision for EV traction battery because it is so large and heavy that it is impractical to position it on current test equipment.

(Jung et al.)

- The current test standards for high voltage batteries, based on quasi-static tests, neither reflect the mechanical loads experienced in the vehicle crash tests nor in the dynamic impact tests. This is true for the specification of a minimum crush of the battery package, and for the correlation of the maximum load to the battery weight. As a result, these battery standards must be modified appropriately, i.e. a minimum load could be specified where no battery cells must be damaged resulting in electric short circuits or electrolyte leakages. The current standards only address the chemical safety performance of individual battery cells.

- As a next step, the differences in load characteristics between the dynamic impact and quasi-static tests must be further analysed, with the ultimate goal to specify relatively simple, reproducible and realistic component tests for traction batteries. Finally, these tests must be verified with different crash loads and different battery types.

(Wech et al., 2011)

- Crash-tests with HEVs housing Nickel-Metal Hydride (NiMH) storage batteries by NCAP organisations have identified no problems with the electrical systems. Lithium-ion (Li-ion) batteries have recently become more common place in EVs. This form of battery has been the subject of negative press due to associated aircraft fires, and laptop computer fires. However, Li-ion batteries in EVs have in-built mechanisms for automatically isolating stored electrical energy and cooling in the event of overheating. Crash tests with a Mitsubishi i-MiEV electric car by ANCAP and Euro NCAP revealed no problems with the battery or the electrical system. In a review of post-crash procedures from manufacturers and emergency response units it was discovered that guidance for dealing with EV accidents and lithium-ion fires was often contradictory.

(Paine.)

- NHTSA crash tested 5 Chevrolet Volts in 2011 and battery pack level impact testing on 6 Chevrolet Volt battery packs. Three separate tests resulted in a sustained fire event either at the vehicle level, or battery pack fires occurred 6 to 7 days after the impact test. One battery test resulted in an electrical arcing event that occurred hours after the impact test, although this event did not result in a sustained fire.

- The findings reported were from standardised tests, typically performed for the New Car Assessment Program (NCAP) and for verification of compliance with the Federal Motor Vehicle Safety Standards (FMVSS) in the USA, therefore providing robust evidence of risks, However, the tests were performed on Chevrolet Volt battery packs and not whole vehicles. No real-world crash data has been reported which indicates that a Chevrolet Volt has suffered a battery induced fire event either immediately after a crash or for an extended time period after a crash.

(Smith, 2012)

- Some concerns have been expressed regarding the “compatibility” of EVs with conventional ICE vehicles in a collision. For example, EVs are usually smaller, but heavier, and have different weight distributions than conventional vehicles. Additional weight is usually due to the rechargeable energy storage system (RESS) and any structural features required to accommodate the RESS, It is common knowledge that if two vehicles collide, less deceleration will be imposed on the heavier vehicle than the lighter vehicle which could lead to greater risks for occupants of lighter vehicles. There is some evidence to suggest that the probability of injury in a hybrid is lower than that in a non-hybrid, possibly due to the greater weight of hybrid vehicles. However mass is not the only factor involved in injury risk. For example, the size of the vehicle, and in particular the ability of the structural ‘crush space’ to absorb the energy of an impact is crucial. EVs may be heavier but they are also typically smaller than ICE vehicles. ‘Compatibility’ is not currently considered in legislation but research is underway to develop suitable test procedures (in particular, the European 7th Framework Project, Frontal Impact and Compatibility Assessment Research, FIMCAR).

(Visvikis, 2012)

Post-impact safety issues

- Post-impact safety issues were discussed by a 'group of interested experts' in 2009, with regards to useful and appropriate amendments to relevant United Nations Regulations.

- UN Regulation 100 specifies requirements for the safety of electric vehicles 'in-use' and the protection of users against electric shock, and is now mandatory for EU type-approval. Amendments to UN Regulations 94 (front impacts) and 95 (side impacts) were completed in 2010 and include requirements for post-impact electrical safety. These have since been adopted by WP.29 (the World Forum for Harmonisation of Vehicle Regulations, a subsidiary of UNECE). Other amendments include UN Regulation 13 and 13-H (emissions), 85 (engine power), and 101 (CO2 emissions).

- A proposal made at the 155th session of WP.29 (the World Forum for Harmonisation of Vehicle Regulations, a subsidiary of UNECE) is concerned with the development of a UN Global Technical Regulation containing safety provisions for the electrical safety. This includes post-impact issues, such as:
  - Electrical isolation
  - Battery integrity
  - Best practices or guidelines for manufacturers and/or emergency responders
  - Battery discharge procedures.

(Visvikis, 2012)

- Electric propulsion technology inherent in EVs carries some potential risks which are unique from conventional ICE vehicles, and which are important for post-impact vehicle safety issues. Rechargeable energy storage systems (RESS) are used to provide electrical energy for the electric propulsion of EVs, and may be realised through batteries, capacitors and electromechanical flywheels. Hazards associated with batteries have been given particular attention, which can include:
  - Electrolyte (or other material) spillage due to cell casing damage;
  - Chemical reaction to extreme temperature or fire, and;
  - Electrical risks such as short circuit, over voltage and voltage reversal.

(Visvikis et al., 2010)

- If an electric vehicle is involved in a collision, the impact could compromise the integrity of the electrical systems and increase the risk of electrical shock. For example, if electrical isolation is damaged such that the positive and negative terminals in the circuit come into contact with the vehicle bodywork, then subsequent human contact with the bodywork will result in electric shock. Protective mechanisms exist to disengage the high-voltage electrical system in the event of a crash thereby reducing the risk of this event. This is also an important mechanism for reducing the risk of fire or explosion following an impact.

  (Visvikis, 2012)

- Additional hazards are presented by EVs powered by lithium ion batteries. Lithium is a highly reactive substance and electrolytes are highly flammable. As a safety measure, manufacturers of lithium ion batteries incorporate internal and external protection mechanisms to reduce the risk, such as fuses, PTCs, built-in weak spots and flame retardants added to the electrolyte.

  (Tjus, 2011)

- The safety of batteries may be assessed via appropriate abuse tests. Issues related to lithium ion batteries have included thermal runaway, electrolyte leaks, smoke, venting, fire and explosion as a result of several abuse tests including overvoltage, overdischarge, heating arcing, crush, nail penetration and internal and external short.

  (Pesaran et al., 2009)

- Lithium ion batteries have also been investigated elsewhere using abuse tests, such as perforation, mechanical crushing, external short circuit, overcharging/overdischarging, overheating, fuel fire immersion and water immersion. The tests are used to characterise the tolerance levels of lithium ion batteries but it has been argued that they do not necessarily offer a measure of battery safety. For example, perforation and overheating abuse tests have been shown to lead to cell venting, but this event does not result in reduced safety of a battery pack which has sufficient protective devices. The authors of this work also argue that few serious incidents relating to lithium ion batteries have been reported despite extensive worldwide use over the last decade. Further advances in battery technology such as iron phosphate positives or lithium titanate negatives have produced greater abuse tolerance thereby increasing safety when used in EVs.

  (Kalhammer et al., 2009)

- However, the risk associated with electric batteries was highlighted in one incident in the USA with a Chevrolet Volt. Three weeks after a pole impact test, the electric caught fire as a result of damage to the battery. Coolant leaked onto electronic components following the impact, and because the battery was not properly discharged the vehicle caught fire whilst it was placed in storage. This illustrates the importance of managing risks associated with battery safety, even after an impact has occurred.

  (Smith, 2012)

- There are a number of properties of hydrogen which are relevant to hydrogen fuel-cell vehicle safety.
    - Hydrogen gas is odourless and colourless meaning it is harder to detect than natural gas and gasoline vapour.
    - Hydrogen burns with a blue flame which is almost undetectable in daylight.
    - The high buoyancy of hydrogen means that it will disperse in the air around 4 times and 10 times faster than natural gas and gasoline vapour, respectively. When mixed with air there is a risk of fire.
    - The small molecular structure of hydrogen gas means it can more easily leak through porous structures.
    - Hydrogen is flammable between 4% and 75% by volume with air. In comparison, gasoline is flammable between 1% and 8% by volume with air.
    - 'Hydrogen embrittlement' can occur following extended exposure of some materials, such as steel, to hydrogen. This can cause leakage or catastrophic failure of that material.

(Visvikis et al., 2010)

- As a result of the chemical composition of hydrogen, hydrogen fuel-cell vehicles carry additional risks. These may be classified as:
    - Physiological (e.g. asphyxiation, thermal burns, frostbite, hypothermia and overpress injury)
    - Physical (e.g. component failures due to low temperature deterioration, thermal contraction and hydrogen embrittlement)
    - Chemical (e.g. burning or explosion)
- The odourless, colourless and tasteless nature of hydrogen gas means that leaks cannot be detected by humans without the use of hydrogen sensors. Unlike natural gas which has added odorants to enable easy detection, current odorants in existence have been shown to contaminate fuel cells, and so are not appropriate for use in vehicles.

(Rigas and Amyotte, 2013)

- Post-crash limits for liquid fuels exist and have been used to benchmark the leakage limits for hydrogen in industry standards, relevant to the use of hydrogen fuel-cell vehicles. However, due to differences in the chemical properties of hydrogen compared with conventional liquid fuels, this benchmark may not be appropriate.
- In one study investigating the properties of hydrogen, the authors concluded that the volume of hydrogen leaked is more important than the leak rate when considering safety implications. Specifically the study recommended:

    - Accumulation of hydrogen in the passenger compartments should be avoided.
    - Multiple sensors may be required to alert passengers of a hydrogen leak.
    - Post-accident devices which vent the passenger compartments are effective.
- The study provides some information on the the likely impact of hydrogen leakage and accumulation in a vehicle, however, as the authors state, “the study is not indicative of how a hydrogen fuel system would perform in a crash” since the tests involved a simulation using conventional vehicles and ‘vehicle compartment simulators’.

(Hennessey et al.)

- An analysis of fire hazards for the existing vehicle fleet and the Emerging Fuel Vehicle (EFV) fleet found that, compared with a rate of 350 fire-related deaths per year as a result of traditional fuel vehicles (ICE), there were 420, 910 and 1300 *predicted* fire-related deaths per year for petrol-electric HEVs, compressed gas vehicles and hydrogen fuel-cell vehicles, respectively. This analysis was performed via predictive methods of risk assessment and was not based on empirical data, however the model suggests an increased risk of fire-related deaths with EVs over conventional ICE vehicles.

(Levy, 2008)

- One study from the USA focuses on some of the safety issues which the fire service may encounter. Electric propulsion systems are associated with new and unanticipated hazards compared to conventional ICE vehicles:
    - One of the biggest challenges for emergency responders is identification of EVs when attending an incident. The exterior body of some EVs and HEVs is not easily distinguishable from conventional ICE vehicles, therefore an accurate risk assessment of the associated hazards may be difficult.
    - The addition of a high-voltage electrical system in EVs is a crucial difference from ICE vehicles which is important for vehicle extrication procedures because of the added risk of electrocution. Cabling for the high-voltage electrical power systems in EVs and HEVs are often coded via bright colours to facilitate clear identification.
    - After isolation, it takes a fixed-period of time for a high-voltage system to fully dissipate. It is therefore recommended that at least 10 minutes is allowed before the system can be deemed safe.
    - Due to their ability to function silently, it is crucial for emergency responders to be certain that they have fully disabled an EV. It is recommended that emergency responders always assume an EV is powered-up, even in the absence of vehicle noise.

- Extinguishing a high-voltage battery fire normally requires either a large volume of water or a 'defensive approach' whereby the battery is allowed to burn and consume itself (as long as there a no further exposures to heat). Battery fires can lead to electrolyte spillage so adequate personal protective equipment (PPE) is imperative.

(Grant, 2010)

Risks associated with low vehicle noise emission

- Some authors have argued that due to the predicted increase of electric and other low-noise vehicles in urban areas, engine noises in these locations are likely to be significantly reduced. It is argued that there may be an increasing number of road traffic accidents between these vehicles and vulnerable road users (with particular emphasis on the elderly, children and those with visual impairments who rely on both visual and auditory signals for perceiving the environment around them), although no evidence of this increase is cited. To reduce the risk of traffic accidents the authors suggest it may be necessary to develop acoustic warning signals, to replace missing engine sound, especially in urban areas.

(Brand et al., 2012)

- An experiment undertaken by the Dresden University of Technology in Germany investigated how visually impaired, blind and sighted participants responded to the sound produced by internal combustion engine (ICE) vehicles, electric vehicles (EV) and hybrid-electric vehicles (HEV). Three groups of pedestrians (sighted, blind and visually impaired) detected the sound of EVs significantly later than ICE vehicles, with the ICE being detected from a distance of approximately 36m and EVs at approximately 14m. The study also looked at manufactured sounds on EVs and found that synthesised noise, despite being 7dB quieter, produced similar reactions to recorded vehicle sound. The study provides useful data on reaction times to different noises, albeit using a fairly small sample (27 sighted subjects and 10 visually-impaired or blind subjects). However, the study was performed in a laboratory and subjects were asked to imagine they were standing on a pedestrian footway waiting to cross the road, so did not accurately replicate conditions found in the real-world. In addition, no information was provided on the speed of the moving vehicles from which sound was recorded, so application of the results to real-world scenarios is not straight-forward.

(Altinsoy, 2013)

- There is an important trade-off between optimal noise levels for health and social well-being and optimal noise for the safety of pedestrians, cyclists and other road users who rely on vehicle noise as a warning sound. From a safety perspective, EVs may sometimes be considered too quiet. Any synthetic sound which is applied to EVs must be able to convey vehicle speed, acceleration/deceleration, and driver intentions. Current research is investigating the best sounds to achieve this.

(Chamard et al., 2012)

- The National Highway Traffic Safety Administration (NHTSA) investigated the rate of crashes between pedestrians and HEVs and ICE vehicles. Accidents involving pedestrians and cyclists involving HEVs and ICE vehicles tended to occur on roadways, in low speed limit areas, during daytime and in clear weather. The study found a higher crash rate with HEVs, with these vehicles being twice as likely to be involved in a slow moving or manoeuvring crash with pedestrians as equivalent ICE vehicles. HEVs were also involved in more slow speed crashes with cyclists than ICE vehicles. At low speeds the noise differences emitted by the ICE and HEV are most different (low tyre or wind noises mean the engine noise – or lack of it – is dominant). Whilst it is possible that noise contributed, the cause of the accidents was not investigated in this study so it cannot be concluded that the higher crash rate attributed to HEVs was due to the lack of engine noise. Furthermore, other than controlling for speed limit, there is no discussion of the location of the collisions investigated so it is possible that the likelihood of encountering pedestrians and cyclists was greater in some scenarios.

(NHTSA, 2009)

- An in-depth review of research literature, standards and legislation concluded that whilst the detectability of electric vehicles moving at low-speed may be lower than for conventional ICE vehicles, there is currently little strong evidence to suggest an increased risk to vulnerable road users (such as cyclists, pedestrians and the visually-impaired). However, it was argued that the number of electric vehicles on the road could rise in the future which may increase the risk to vulnerable road users. Synthetic noise has been developed to provide a warning to road users in the absence of engine noise; artificial engine sounds appear to be favoured over other types of noise.

(Visvikis et al., 2010)

- A research project conducted by the Transport Research Laboratory, commissioned by the Department for Transport, reviewed vehicle accident statistics to determine whether the accident risk posed by EVs differed from that posed by traditional ICE vehicles. The key findings were:
    - Considering passenger cars and car-derived vans, the likelihood of being involved in a collision with a pedestrian was equal for EVs/HEVs and traditional ICE vehicles.
    - It appears that whilst the relative number of EVs/HEVs involved in any accident is smaller than ICE vehicles, proportionately more of the EV/HEV accidents involve pedestrians. This may be due to the usage patterns of EV/HEV which gravitate towards urban areas.

  - Only two EV/HEV accidents involving a pedestrian with a disability were identified, so conclusions about risk for visually-impaired road users are not possible.
  - It was not possible to include information on vehicle speed, location or manoeuvre nor was it possible to differentiate between EVs and HEVs. Hence, whether or not HEVs involved in accidents with pedestrians were running on electric power or the conventional ICE is unknown, therefore it cannot be concluded that low noise emission was a contributory factor to the accidents.
- Measurements of vehicle noise were also conducted with EVs, HEVs and conventional ICE vehicles at a range of speeds in the study. It was concluded that “peaks in the pass-by noise spectra related to exhaust noise” were the only differences in sound profile identified between the various types of vehicle.

(Morgan et al., 2011)

- Two field studies in Germany examined the perceptions of low noise emission EVs of 70 participant drivers. Interviews and questionnaires were used to gauge driver opinions before driving an EV for the first time and after three and six months of driving an EV. Incidents related to low noise emission were rare, and typically occurred at low speeds. Responses also revealed driver perception of risk due to low noise reduced with increasing driving experience, whilst the perception of driver comfort due to low noise increased over the 6-month driving period. The study provides valuable information on driver perceptions of EV noise emissions through investigation of real-world EV driving experience.

(Cocron and Krems, 2013)

- One study investigated EV test drivers and their experiences relating to the lack of noise emission. A naturalistic driving study followed 40 participants driving an EV over a 6-month period and found that:
  - Drivers were aware of the low noise emission and aware of the associated potential dangers.
  - Drivers adapted their driving as a result of the low noise emission.
  - The few incidents which were reported typically involved pedestrians and cyclists and occurred at very low speed with no injuries sustained. At higher speeds there are other sound cues from the vehicle (e.g. tyre noise, wind etc.), so low noise emission is largely an urban issue in environments with low speed limits.

- Whilst a naturalistic driving study is advantageous in that it allows investigation of driver behaviours and experiences in a real-world setting, it is limited in that there is no control of confounding factors. For example, it is not possible to conclude that low noise emission was a contributory factor to the reported incidents between EVs and pedestrians and cyclists. It is also possible that involvement in the research raised the awareness of safe driving practices in drivers, leading them to adopt more cautious behaviours whilst participating in the study.

(Cocron et al., 2010)

- Three studies were designed by Wogalter et al. (2013) to investigate concerns related to low vehicle noise emission.
    - In the first study, 378 participant questionnaires indicated “substantial positive interest” in EVs, but approximately half of respondents indicated that a silent vehicle would bother them as a pedestrian. The most commonly recommended type of sounds to add to silent vehicles were ‘engine’ and ‘hum’ sounds, but there was also a high degree of acceptance for no sound to be added.
    - The second study investigated preferences for types of sounds in greater detail. 316 participants rated 14 sounds in terms of their acceptability for adding to low noise emission vehicles. As with study 1, the highest rated sounds were ‘engine’ and ‘hum’. ‘No added sound’ was rated as significantly less preferable than engine and hum sounds.
    - Studies 1 and 2 examined EV and sound preferences using only questionnaires and descriptive terms; no actual sounds were heard by participants. The third study offered greater ecological validity by showing 24 participants a video of a moving 2007 Toyota Prius coupled with one of six categories of sound: engine, horn, hum, siren, whistle and white noise (it should be noted that these conditions differ from real-world pedestrian experiences of EV noise). The preferences for each synthetic sound addition were again investigated, and findings revealed that, like the earlier studies, engine noise was most preferable as an auditory cue, followed by hum sounds and white noise.

(Wogalter et al., 2013)

- A study was performed to investigate the responses of blind participants to a passing electric vehicle with a) no noise added; b) idling engine noise added, and; c) a repeating bell and engine noise added. Compared with a traditional ICE vehicle, the loss of engine noise emitted from an electric vehicle significantly reduced the ease with which blind participants were able to identify approaching vehicles. However, the addition of synthetic engine noise was found to be effective at aiding vehicle identification. All conditions tested in the study involved the vehicle travelling at 15 mph and passing participants at a distance of 15 feet. The performance of blind participants measured here cannot be easily extrapolated to other distances or vehicle speeds: it is possible that the effect of vehicle noise would be even more important at higher speeds but this was not investigated in this study.

  (Goodes et al., 2008)

- Fourteen adults with visual impairments were asked to respond to three different passing vehicles in a randomised trial. The three vehicles tested were: a standard HEV, an HEV with added Vehicle Sound for Pedestrians (VSP), and an ICE vehicle. In both a forward-moving and backward-moving vehicle detection test, the detection distances for the HEV with added VSP and for the ICE vehicle were significantly longer than for the standard HEV with no additional noise. These findings suggest that participants were not as effective at detecting the HEV as a standard ICE vehicle, but were aided by the addition of synthetic vehicle noise (i.e. VSP). Interestingly, there were no differences in detection distances between two different test sites with low and high levels of background noise.

  (Kim et al., 2012)

- A laboratory experiment was set-up to investigate the effect of adding different types of warning sounds to the recorded noise of a passing EV on detectability compared with a standard diesel ICE vehicle. Sound stimuli were designed to investigate three parameters of timbre (tonal content, frequency detuning and amplitude modulation). Listeners were required to signal when they detected the arrival of each car by pressing a button on a computer. Responses times were highly variable across the group of participants, but the study showed that the addition of some types of sound offered improved detectability of the EV, such that the EV was equally detectable as the conventional ICE. However, other types of sound failed to improve the detectability of the EV, despite offering similar sound pressure levels. This research indicates that the composition of the warning sound, and not the volume of the sound, is the key factor for improving pedestrian safety, although, like other laboratory studies in this area the study lacks ecological validity.

  (Parizet et al., 2013)

- To address concerns of low noise emission increasing risk for vulnerable road users, especially visually-impaired pedestrians, the approaching Vehicle Sound for Pedestrians (VSP) system has been developed by Nissan. The purpose of this system is to produce a sound which improves detectability of the vehicle for pedestrians, whilst also satisfying driver requirements and maintaining a quiet environment for neighbourhoods. Designed for implementation in Nissan's first mass produced Electric Vehicle, the VSP emits one type of sound during forward motion, another type during 'take-off', when the vehicle first begins to move and a third type of sound for reverse motion. The characteristics of the sound profile utilise knowledge of human ear sensitivity, age-related hearing loss, typical background noise conditions and visually-impaired pedestrian feedback and preferences gathered by surveys in Japan and USA.

  (Tabata et al.)

- The addition of warning sounds to low noise emission vehicles may only be necessary during a 'transition' phase until the majority of vehicles on the road are classified as 'low-noise', since after this point the level of public awareness of low-noise vehicles will alter. A warning sound system designed to replace the absence of an ICE should be able to:
  - Draw the attention of vulnerable road users.
  - Be distinguishable from other audible signals in the environment, i.e. it should differ in sound pressure level and in sound profile from a conventional car horn.
  - Contain information on the vehicle speed, including whether it is accelerating or decelerating.

  (Voigt et al.)

The impact of adding synthetic sound to low noise emission vehicles on driver stress was investigated by the University of Idaho. Through physiological measures (galvanic skin response and heart rate variance) and self-report questionnaires (Short Stress State Questionnaire – SSSQ) researchers examined driver stress whilst operating a Nissan HEV with one of three sound profiles (no added warning sound, manual addition of warning sound via vehicle horn, and automatic addition of warning sound via Nissan VSP system). The study found that the automated VSP system was preferred by drivers, causing less stress than when reliant on a manual warning for pedestrians via the vehicle horn.

(Cottrell and Barton, 2012)

In a study with 15 visually-impaired participants, the addition of a VSP alert sound to a HEV resulted in significantly faster and more reliable detection than an identical vehicle with no VSP system and a conventional ICE vehicle. However, no differences were observed in the ability of participants to discriminate between the intended pathway of the vehicles (i.e. whether they turned right at traffic lights or went straight ahead). The study suggests that whilst the addition of a VSP system may enable visually-impaired pedestrians to quickly detect a vehicle, it may not necessarily reduce the risk of collision, for example where vehicles make a right-turn into a side road with pedestrians present.

(Kim et al., 2012)

In a summary of literature relating to low noise emission in EVs, it is noted that the World Forum for Harmonisation of Vehicle Regulations has "determined that vehicles present a danger to pedestrians", prompting the Working Party on Noise to develop actions necessary to mitigate those risks.

(Visvikis, 2012)

Gaps in the evidence

Electric vehicle technology is still relatively new to the market. As a result there are a number of gaps in the literature surrounding the safety of EVs. This includes:

- A lack of research comparing the risk of occupant injury in electric vehicles on the road with conventional ICE vehicles.
- There is not enough evidence to confirm that the rate of accidents involving vulnerable road users differs for electric vehicles and conventional ICE vehicles.
- Current investigation into accident rates cannot confirm that the lack of noise emission is a causal factor in the accidents between vulnerable road users and electric vehicles.
- Risks associated with high-voltage electric batteries have been demonstrated in controlled impact tests, but there is little evidence of the frequency of this risk in real-world road traffic accidents.

References

(References are listed by order given in the review synthesis).

Title:	**Passive safety in electric vehicles from a structural perspective**
Published:	Lassfolk, T., Barden, A., Seidel, K., Lesniewicz, P., & Asensio, M. (2011)
Link: **Free/priced:**	http://upcommons.upc.edu/handle/2099.1/13732 Priced
Objectives:	To provide an in-depth investigation of the structural behaviour in electric vehicles, from a passive safety perspective
Methodology:	• Literature review
Key Findings:	• The shape of the battery compartment directly affects the behaviour of the electric vehicles structure • It is important to keep the compartment water proof by adding a layer of some kind of rubber material to the shell • The battery has a higher tolerance to move when fastened with belts than with usual bolt fixings points to the electric vehicles body, making the compartment absorb more energy in a crash
Keywords:	Passive safety, electric vehicle, structural behaviour, battery
Comments:	

Title:	**Safety considerations for electric vehicles and regulatory activities**
Published:	Visvikis, C. (2012) EVS26 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium
Link: **Free/priced:**	No online link exists. Free
Objectives:	To explore the potential hazards with electric vehicles and how the risks to users are mitigated by European Union and United National type-approval regulations
Methodology:	• Literature review
Key Findings:	• The main regulatory acts for EU type-approval tend to lag behind the corresponding UN Regulations • The current approach in the framework directive is to permit either the EU Directive or the UN Regulation to be used • A proposal has been made to develop a UN Global Technical Regulation on electric vehicles • A range of safety features are typically used to ensure the safety of occupants or other persons • A collision could compromise the electrical safety measures on an electric vehicle, increasing the risk of electric shock for the occupants • There are a range of potential hazards associated with rechargeable energy storage systems • There is some public concern about the effects of electromagnetic fields on human health, particularly with respect to fields from mobile phones and power lines
Keywords:	Electric vehicles, regulation
Comments:	Overview of safety considerations for electric vehicles

Title:	**Safety requirements for small motorised alternative vehicles.**
Published:	Paine, M. NHTSA, 2011
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000108.pdf Free
Objectives:	To review the types of 'alternative vehicles' that are available, or are under development, the limitations of the infrastructure on which they might be used and the safety issues arising from a mix of conventional road/path users and 'alternative vehicles'.
Methodology:	• Literature review.
Key Findings:	• There is scope for achieving a global or national standard that will be compatible with existing infrastructure and will ensure that 'alternative vehicles' can operate safely amongst other infrastructure users.
Keywords:	Safety requirements, alternative vehicles .
Comments:	

Title:	**Electric vehicles: Review of type-approval legislation and potential risks**
Published:	Visvikis, C., Morgan, P., Boulter, P., Hardy, B., Robinson, B., Edwards, M... & Pitcher, M. (2010). TRL
Link: **Free/priced:**	http://www.emic-bg.org/files/report_electric_vehicles_en.pdf Free
Objectives:	To asses risks associated with electric propulsion not covered by legislation and provide recommendations on appropriate actions.
Methodology:	An in-depth review of research literature, standards and legislation.
Key Findings:	• Whilst the detectability of electric vehicles moving at low-speed may be lower than for conventional ICE vehicles, there is currently little strong evidence to suggest an increased risk to vulnerable road users (such as cyclists, pedestrians and the visually-impaired). • However, it was argued that the number of electric vehicles on the road could rise in the future which may increase the risk to vulnerable road users. • Synthetic noise has been developed to provide a warning to road users in the absence of engine noise; artificial engine sounds appear to be favoured over other types of noise.
Keywords:	EVs, risk, legislation, vulnerable road users, noise
Comments:	

Title:	**Integration issues of cells into battery packs for plug-in and hybrid electric vehicles**
Published:	Pesaran, A.A., Kim, G.H., & Keyser, M. (2009) National Renewable Energy Laboratory
Link: **Free/priced:**	http://www.nrel.gov/vehiclesandfuels/energystorage/pdfs/45779.pdf Free
Objectives:	To discuss mechanical, electrical, and thermal integration issues and vehicle interface issues that could impact the cost, life, and safety of the lithium ion battery system.
Methdology:	• Review comparing the advantages and disadvantages of using many small cells versus few large cells and using prismatic cells versus cylindrical cells
Key Findings:	• Integration of cells into modules and then into battery packs is critical in achieving optimum battery cost, performance, and life • Smaller capacity cells allow for easier packaging of the battery system but result in a higher number of interconnects and failure points • Smaller capacity cells are easier to keep isothermal due to their smaller size. However, providing cooling air of a consistent velocity and temperature to the cells becomes a more difficult problem • Incorporating larger capacity cells in a hybrid electric vehicle or plug-in electric vehicle limits the number of interconnects, but also limits how the cells can be packaged within a vehicle • A computer-aided-engineering tool must be developed to address integration issues
Keywords:	Lithium battery, battery management, cooling, electric drive, modelling, thermal management
Comments:	Discusses integration of cells into battery packs

Title:	**BatMan: Battery Health and Safety Management**
Published:	Tjus, M. (2011) Bochum University
Link: **Free/priced:**	http://mechatronika.polsl.pl/owd/pdf2011/172.pdf Free
Objectives:	To discuss the first testing and plans for a Battery Management System for electric vehicles belonging to a project at Hochschule Bochum
Methodology:	• Exploratory review of types of battery, battery management and testing
Key Findings:	• The BMS-IC from Texas Instruments shows promise in its functions and it has a high level of accuracy and flexibility
Keywords:	Battery management
Comments:	Review of battery health and safety management

Title:	**Myths and facts about hydrogen hazards**
Published:	Rigas, F., & Amyotte, P. (2013) The Italian Association of Chemical Engineering
Link: **Free/priced:**	http://www.aidic.it/lp2013/webpapers/36rigas.pdf Free
Objectives:	To contribute to knowledge of hazardous properties of hydrogen and offer a comprehensive overview of issues of this new energy carrier
Methodology:	• Literature review
Key Findings:	• Hydrogen has been used and stored safely in industry for a long time as compressed gas or liquefied hydrogen • The low accident rate may be due to stricter safety measures taken for this hazardous material as is the case in other industrial sectors such as the explosives industry
Keywords:	Hydrogen hazards
Comments:	Outline of the myths and facts of hydrogen hazards

Title:	**Incidence of pedestrian and bicyclist crashes by hybrid electric passenger vehicles**
Published:	U.S. Department of Transport, National Highway traffic safety administration (2009)
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/Pubs/811204.PDF Free
Objectives:	The National Highway Traffic Safety Administration (NHTSA) investigated the rate of crashes between pedestrians and HEVs and ICEs.
Methodology:	Data from the NHTSA's State Data System were used to acquire pedestrian and cyclist crashes.
Key Findings:	• The study found a higher crash rate with HEVs being twice as likely to be involved in a slow moving or manoeuvring crash with pedestrians than equivalent ICEs. • HEVs were also involved in more slow speed crashes with cyclists than ICEs. • At these speeds the noise differences emitted by the ICE and HEV are most different (low tyre or wind noises mean the engine noise – or lack of – is dominant). • Participants were able to identify the direction of an ICE approach much sooner than a HEV.
Keywords:	EV, hybrid, crashes, pedestrians, cyclists
Comments:	

Title:	**Assessing the perceived safety risk from quiet electric and hybrid vehicles to vision-impaired pedestrians**
Published:	Morgan, P. A., Morris, L., Muirhead, M., Walter, L. K., & Martin, J. (2011), TRL.
Link: **Free/priced:**	https://trl.co.uk/reports/PPR525 Free
Objectives:	A research project conducted by the Transport Research Laboratory, commissioned by the Department for Transport, reviewed vehicle accident statistics to determine whether the accident risk posed by EVs differed from that posed by traditional ICE vehicles.
Methodology:	• Analysis of accident statistics • Comparison of measurements of vehicle noise for EVs, HEVs and conventional ICE vehicles at a range of speeds. • A small-scale subjective assessment of the noise from these vehicles with visually impaired participants
Key Findings:	The key findings were: • Considering passenger cars and car-derived vans, the likelihood of being involved in a collision with a pedestrian was equal for EVs/HEVs and traditional ICE vehicles. • It appears that whilst the relative number of EVs/HEVs involved in any accident is smaller than ICE vehicles, proportionately more of the EV/HEV accidents involve pedestrians. This may be due to the usage patterns of EV/HEV which gravitate towards urban areas. • Only two EV/HEV accidents involving a pedestrian with a disability were identified, so conclusions about risk for visually-impaired road users are not possible. • It was not possible to include information on vehicle speed, location or manoeuvre nor was it possible to differentiate between EVs and HEVs. Hence, whether or not HEVs involved in accidents with pedestrians were running on electric power or the conventional ICE is unknown, therefore it cannot be concluded that low noise emission was a contributory factor to the accident. • “Peaks in the pass-by noise spectra related to exhaust noise” were the only differences in sound profile identified between the various types of vehicle.
Keywords:	Risk, quiet vehicles, EV, hybrid vehicle, noise, collision, accidents

Title:	**Hybrid and electric low-noise cars cause an increase in traffic accidents involving vulnerable road users in urban areas**
Published:	Brand, S., Petri, M., Haas, P., Krettek, C., & Haasper, C. (2012). International journal of injury control and safety promotion, (ahead-of-print), 1-3.
Link: **Free/priced:**	http://www.tandfonline.com/doi/abs/10.1080/17457300.2012.733714 Priced
Objectives:	To discuss the effects of low-noise hybrid and electric cars on traffic accidents.
Methodology:	Discussion and evaluation of current literature and expert knowledge.
Key Findings:	Due to the predicted increase in electric and other low-noise vehicles in urban areas, engine noises in these areas are likely to be significantly reduced. It is therefore expected that there will be an increasing number of road traffic accidents between these vehicles and vulnerable road users (with particular emphasis on the elderly, children and those with visual impairments who rely on both visual and auditory signals for perceiving the environment around them). To reduce the risk of traffic accidents it may be necessary to develop acoustic warning signals, to replace missing engine sound, especially in urban areas.
Keywords:	Low-noise cars, traffic accidents, acoustic signals, vulnerable road user
Comments:	

Title:	**The detectability of conventional, hybrid and electric vehicle sounds by sighted, visually impaired and blind pedestrians**
Published:	Altinsoy, E. (2013). Dresden University of Technology.
Link: **Free/priced:**	http://www.ias.et.tu-dresden.de/ias/fileadmin/user_upload/akustik/Forschung/altinsoy_neu/21_Altinsoy_Internoise.pdf Free
Objectives:	An experiment undertaken by the Dresden University of Technology in Germany investigated how visually impaired, blind and sighted participants responded to the sound produced by internal combustion engine (ICE) vehicles, electric vehicles (EV) and hybrid-electric vehicles (HEV).
Methodology:	The reaction time of thirty seven participants, aged between 20-69 years was measured.
Key Findings:	Three groups of pedestrians (sighted, blind and visually impaired) detected the sound of EVs significantly later than ICE vehicles, with the ICE being detected from a distance of approximately 36m and EVs at approximately 14m. The study also looked at manufactured sounds on EVs and found that synthesised noise, despite being 7dB quieter, produced similar reactions to recorded vehicle sound.
Keywords:	Electric vehicle, detectability, blind
Comments:	

Title:	**On the hazard of quiet vehicles to pedestrians and drivers**
Published:	Wogalter, M. S., Lim, R. W., & Nyeste, P. G. (2013). Applied ergonomics (in press).
Link: **Free/priced:**	http://www.sciencedirect.com/science/article/pii/S0003687013001567 Priced
Objectives:	To explore interests and concerns about electric vehicles.
Methodology:	A survey with 380 people was conducted.
Key Findings:	In a survey exploring attitudes to EVs participants frequently reported that lack of noise was a concern with 70% believing them to be a danger to pedestrians
Keywords:	EV, quiet vehicles, accident risk, pedestrians
Comments:	

Title:	**Impact of adding artificially generated alert sound to hybrid electric vehicles on their detectability by pedestrians who are blind**
Published:	Kim, D. S., Emerson, R. W., Naghshineh, K., Pliskow, J., & Myers, K. (2012). Journal of rehabilitation research and development, 49(3), 381.
Link: **Free/priced:**	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3396425/ Free
Objectives:	To investigate the effect that adding an artificially generated sound had on the detectability of an HEV.
Methodology:	Fourteen adults with visual impairments were asked to respond to three different passing vehicles in a randomised trial.
Key Findings:	• The three vehicles tested were: a standard HEV, an HEV with added Vehicle Sound for Pedestrians (VSP), and an ICE vehicle. • In both a forward-moving and backward-moving vehicle detection test, the detection distances for the HEV with added VSP and for the ICE vehicle were significantly longer than for the standard HEV with no additional noise. • These findings suggest that participants were not as effective at detecting the HEV as a standard ICE vehicle, but were aided by the addition of synthetic vehicle noise (i.e. VSP).
Keywords:	Alert sound, blind, detectability, hybrid electric vehicle, orientation and mobility, pedestrian safety, quiet car, vehicle detection, Vehicle Sound for Pedestrian, visually impaired.
Comments:	

Title:	**The future of vehicle safety and sustainable transportation**
Published:	Widmann, U., & Seibert, D (2012).
Link: **Free/priced:**	http://trid.trb.org/view.aspx?id=1147415 Priced
Objectives:	Presentation to discuss the benefit of available driver assistance systems such as lane department warning, adaptive cruise control, braking guard and lane change assist. Also covers future trends in sustainable transportation including electric and hybrid vehicles.
Methodology:	• Discussion of key areas
Key Findings:	• Crash relevant high voltage components in electric vehicles • Safety aspects in e-vehicle crashes • Safety standards
Keywords:	Electric vehicles, sustainability.
Comments:	Presentation covering key areas for electric vehicles and sustainability.

Title:	**Fire fighter safety and emergency response for electric drive and hybrid electric vehicles: Final report**
Published:	Grant, C.C. (2010). The Fire Protection Research Foundation.
Link: **Free/priced:**	http://drum.lib.umd.edu/handle/1903/8311 Free
Objectives:	To assemble and disseminate best practice information for fire fighters and fire ground incident commanders to assist in their decision making process for handling electric and hybrid electric vehicles.
Methodology:	• Review of best practice identifying the fundamental principles and key details involving fire/rescue tactics and strategy, summary of core basics, training needs and areas requiring further research.
Key Findings:	• The key areas for emergency responders to consider are establishing standardised methods and approaches, treating the area as no different to other conventional technology advancements, defaulting to the worst-case approach until proven otherwise and enabling electronic transmittal of accurate dispatch data.
Keywords:	Fire, electric vehicle, hybrid vehicle.
Comments:	Fire fighter safety and response to electric and hybrid vehicles.

Title:	**Analysis of perception, adaptive design and rating of warning signals in different soundscapes**
Published:	Voigt, K. S., & Schulte-Fortkamp, B. (n.d.)
Link: **Free/priced:**	http://users.ugent.be/~bdcoense/content/data/pdf/conference/37_VoigtDAGA11_draft.pdf Free
Objectives:	To discuss current work on the design of warning signals to increase road user safety.
Methodology:	Discussion of current literature and expert knowledge.

Key Findings:	• The addition of warning sounds to low noise emission vehicles may only be necessary during a 'transition' phase until the majority of vehicles on the road are classified as 'low-noise', since after this point the level of public awareness of low-noise vehicles will alter.
	
	• A warning sound system designed to replace the absence of an ICE should be able to:
	
	    o Draw the attention of vulnerable road users;
	
	    o Be distinguishable from other audible signals in the environment, i.e. it should differ in sound pressure level and in sound profile from a conventional car horn;
	
	    o Contain information on the vehicle speed, including whether it is accelerating or decelerating.

Keywords:	Vehicle noise emission, EV, hybrid vehicle, warning signal, pedestrians, cyclists, safety.
Comments:	

Title:	**Design of Electric or Hybrid vehicle alert sound system for pedestrian.**
Published:	Chamard, J. C., & Roussarie, V. (2012). Proceedings of the Acoustics 2012 Nantes Conference.
Link: **Free/priced:**	http://hal.archives-ouvertes.fr/docs/00/81/13/53/PDF/hal-00811353.pdf Free
Objectives:	There is an important trade-off between optimal noise levels for health and social well-being and optimal noise for the safety of pedestrians, cyclists and other road users who rely on vehicle noise as a warning sound. This study aimed to answer the question of how to inform road users of the movements of the electric or hybrid vehicle (speed, acceleration, etc.) without disturbing road users.
Methodology:	Testing was conducted on a track at the test centre located in La Ferté Vidame. A diesel and electric vehicle was used. Ten participants took part and had their eyes masked and were immersed in a background (behind) with two speakers and a subwoofer. Two questions were asked about the detection and another about danger and the risk.
Key Findings:	From a safety perspective, EVs may sometimes be considered too quiet. Any synthetic sound which is applied to EVs must be able to convey vehicle speed, acceleration/deceleration, and driver intentions. Current research is investigating the best sounds to achieve this.
Keywords:	Low-noise cars, acoustic signals, pedestrian, electric & hybrid vehicles
Comments:	

Title:	**The silence of electric vehicles – blessing or curse?**
Published:	Cocron, P., Bühler, F., Franke, T., Neumann, I., & Krems, J. F. (2011, January). In Paper accepted to appear in Proceedings of the 90th Annual Meeting of the Transportation Research Board, Washington, DC.
Link: **Free/priced:**	http://www.tu-chemnitz.de/hsw/psychologie/professuren/allpsy1/pdf/Cocron%20et%20al.,2011.pdf Free
Objectives:	One study investigated EV test drivers and their experiences relating to the lack of noise emission.
Methodology:	A naturalistic driving study followed 40 participants driving an EV over a 6-month period.
Key Findings:	• Drivers were aware of the low noise emission and aware of the associated potential dangers. • Drivers adapted their driving as a result of the low noise emission. • The few incidents which were reported typically involved pedestrians and cyclists aan occurred at very low speed with no injuries sustained. At higher speeds there are other sound cues from the vehicle (e.g. tyre noise, wind etc.), so low noise emission is largely an urban issue in environments with low speed limits.
Keywords:	EV, low-noise cars, accidents
Comments:	

Title:	**Investigation into the detection of a quiet vehicle by the blind community.**
Published:	Goodes, P., Bai, Y., & Meyer, E. (2009). SAE International.
Link: **Free/priced:**	http://papers.sae.org/2009-01-2189/ Priced
Objectives:	To understand how low noise vehicles affect the safety of blind participants.
Methodology:	A study was performed to investigate the responses of blind participants to a passing electric vehicle with a) no noise added; b) idling engine noise added, and; c) a repeating bell and engine noise added.
Key Findings:	• Compared with a traditional ICE vehicle, the loss of engine noise emitted from an electric vehicle significantly affected the ability of blind participants to identify approaching vehicles. • However, the addition of synthetic engine noise was found to be effective at aiding vehicle identification.
Keywords:	Design engineering and styling, noise, electric motors, pedestrian injuries.
Comments:	

Title:	**Detectability and annoyance of warning sounds for electric vehicles.**
Published:	Parizet, E., Robart, R., Chamard, J. C., Schlittenlacher, J., Pondrom, P., Ellermeier, W., & Hatton, G. (2013). In Proceedings of Meetings on Acoustics (Vol. 19, p. 040033).
Link: **Free/priced:**	http://scitation.aip.org/content/asa/journal/poma/19/1/10.1121/1.4800182 Free
Objectives:	A laboratory experiment was set-up to investigate the effect of adding different types of warning sounds to the recorded noise of a passing EV on detectability compared to a standard diesel ICE vehicle.
Methodology:	• Sound stimuli were designed to investigate three parameters of timbre (tonal content, frequency detuning and amplitude modulation). • Listeners were required to signal when they detected the arrival of each car by pressing a button on a computer.
Key Findings:	• The study showed that the addition of some types of sound offered improved detectability of the EV, such that the EV was equally detectable as the conventional ICE. • However, other types of sound failed to improve the detectability of the EV, despite offering similar sound pressure levels. • This research indicates that the composition of the warning sound, and not the volume of the sound, is the key factor for improving pedestrian safety.
Keywords:	Acoustic sensing, acoustic noise, electric vehicles, timbre, music perception, pitch, road vehicle noise, time measurement.
Comments:	

Title:	**Development of body structure for crash safety of the newly developed electric vehicle.**
Published:	Uwai, H., Isoda, A., Ichikawa, H., & Takahashi, N.
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000199.pdf NHTSA, 2011 Free
Objectives:	To describe the development of a new electric vehicle which achieves electric safety and occupant protection performance in addition to maintaining enough cruising distance and cabin space.
Methodology:	• Outline of the newly developed electric vehicle system and component parts.
Key Findings:	• Layout and body structure offers protection of the high-voltage components. • High voltage shutdown is achieved by the impact sensing system. • Electric shock is prevented by fuses which prevent short circuits. • To achieve longer cruising distance, it is important to further reduce the total mass without compromising the electrical system safety and occupant protection performance.
Keywords:	Crash safety, body structure, electric vehicles.
Comments:	

Title:	**Current status and future development of safety standards for electric vehicles.**
Published:	Guibin, L. & Yingnan, Z. (2012).
Link: **Free/priced:**	www.cspress.cn/u/cms/www/201208/170848106sy9.pdf NHTSA Free
Objectives:	An overview of the current status and future development of safety standards for electric vehicles.
Methodology:	• Review of standards
Key Findings:	• Electric vehicles have the same safety problems as conventional automobiles. • Special safety problems of electric vehicles have attracted the attention of the world and safety standard systems have already been established. • China has its own safety standards system covering pure electric vehicles, hybrid and fuel cell ones.
Keywords:	Electric vehicles, safety, standards.
Comments:	Review of standards.

Title:	**Crash safety of hybrid and battery electric vehicles.**
Published:	Justen, R., Schöneburg, R.
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000096.pdf Free
Objectives:	To describe Daimler's concept for crash safety of hybrid and electric vehicles.
Methodology:	• Description of Daimler's concept.
Key Findings:	• Full description of Daimler's concept described.
Keywords:	Crash safety, hybrid and battery electric vehicles.
Comments:	

Title:	**A study on fire resistance test procedure for traction battery.**
Published:	Jung, H., Kim, K., Lee, K., & Kwon, H. Korea Automobile Testing & Research Institute.
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv23/23ESV-000353.PDF Free
Objectives:	To study a fire resistance test procedure for traction battery.
Methodology:	• The current KMVSS traction battery fire resistance test, draft of ECE R-100 RESS fire resistance test in outside and draft of GTR/SGS test procedure for hydrogen storage fire test were analysed.
Key Findings:	• The current procedure of KSVSS fire resistance test is appropriate for a small scale of hybrid electric vehicle traction battery when a flame temperature control is adjusted and a test specimen is place on the test equipment. • A problem occurs when the electric vehicle traction batter is tested, because it is so large and heavy that a test specimen is hard to be placed on the test equipment. The flame temperature is difficult to adjust because the top of the burner is open.
Keywords:	Electric vehicles, battery, fire resistance.
Comments:	Study on fire resistant test procedures for traction batteries.

Title:	**Crash safety aspects of HV batteries for vehicles**
Published:	Wech, L., Richter, R., Justen, R., & Schöneburg, R.
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000302.pdf NHTSA, Paper No 11-0302, 2011 Free
Objectives:	To assess the safety performance of high voltage batteries in severe crashes.
Methodology:	• Comprehensive series of dynamical impact tests with all types and sizes of high voltage batteries used in the current Mercedes-Benz hybrid and electric vehicles.
Key Findings:	• Despite the high loads and the resulting major battery intrusions, no thermal or electric reactions occurred, neither short circuits, nor electrolyte leakages, nor fire or explosion. • A very high crash safety performance was demonstrated for all the batteries.
Keywords:	Crash, high voltage battery.

Title:	**Chevrolet volt battery incident overview report.**
Published:	Smith, B. (2012). National Highway Traffic Safety Administration.
Link: **Free/priced:**	http://www.nhtsa.gov/staticfiles/nvs/pdf/Final_Reports.pdf Free
Objectives:	To test vehicles with new technology to assure acceptable crash performance and occupant protection. With electric vehicles emerging the agency decided to test vehicles equipped with lithium-ion battery chemistries that were being introduced for sale.
Methodology:	• Crash test program
Key Findings:	• Intrusion damage to the battery with coolant leakage followed by rollover has the potential to expose energised battery components to the battery cooling solution. • A fire hazard is produced when the electrically conductive liquid cooling solution comes in contact with the energised battery components. • The fires that occurred during the test series tool approximately a week to develop, but could have occurred sooner under different circumstances.
Keywords:	Battery, incident.
Comments:	Crash test program.

Title:	**Plug-in hybrid electric vehicles: Promise, issues and prospects.**
Published:	Kalhammer, F.R., Kamath, H., Duvall, M., Alexander, M., & Jungers, B. (2009).
Link: **Free/priced:**	http://www.e-mobile.ch/pdf/2010/EVS-24-5040526.pdf EVS24, 2009 Free
Objectives:	To address the issues surrounding the barriers to the acceptance of plug-in hybrid electric vehicles.
Methodology:	• Examines the main technical, cost and infrastructure issues faced by plug-in electric vehicles.
Key Findings:	• Progress in every aspect of plug-in electric vehicle technology but especially in lithium ion batteries has established the technical basis for development of plug-in electric vehicles with competitive performance and reliability.
Keywords:	Plug-in hybrid electric vehicles, lithium battery, battery cost, battery life, battery charging infrastructure, energy availability.
Comments:	Review of plug-in hybrid electric vehicles.

Title:	**Post-crash fuel leakage and fire safety experiments for hydrogen vehicles.**
Published:	Hennessey, B., Reuther, J.J., John, J.S., Shawcross, P.E., & Kimmel, G. U.S. National Highway Traffic Safety Administration (NHTSA), Paper Number 11-0439, 2011
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000439.pdf Free
Objectives:	To access the safety of the proposed allowable leak rate for hydrogen, through leak ignition experiments in and around vehicles and vehicle compartment simulators.
Methodology:	• Experiments: Leak rate vs. concentration build-up in and around an intact automobile; Ignition and combustion tests in an automobile compartment simulator containing known concentrations of hydrogen; full-scale leak, ignition and fire tests on intact and crashed automobiles.
Key Findings:	• Data indicated that leak rate was not the most important metric when identifying minimum allowable post-crash leak rate. Instead, the volume of hydrogen leaked into the automobile compartments to accumulate locally to 5%, or to a level exceeding the lower flammability limit of 4% is important. • All accumulation of hydrogen within passenger compartments should be avoided. • More than one sensor in vehicle compartments may be required for alarm purposes. • Vehicles that vent passenger compartments upon impact are warranted. • Flammability tests on fabrics exposed to hydrogen or hydrogen flames may have merit.
Keywords:	Post-crash, fire, hydrogen vehicles.
Comments:	Hydrogen vehicle experiments.

Title:	**Fire safety in today's and tomorrow's vehicles.**
Published:	Levy, K.M. (2008).
Link: **Free/priced:**	http://drum.lib.umd.edu/handle/1903/8311 Free
Objectives:	To consider fire hazards in the existing vehicle fleet and uses failure modes and effects analyses of three generic designs to identify and rank potential fire hazards in the emerging fuel vehicle fleet.
Methodology:	• A statistics based predictive quantitative risk assessment framework and estimated uncertainty analysis was undertaken to present risk of the emerging fuel vehicle fleets.
Key Findings:	• Hybrid vehicles provide only a moderately greater fire death risk than traditional fuel vehicles, an increase by an estimated factor of 1.2. • Compressed fuel vehicles have a much greater relative risk. • The predicted risk uncertainty for the compressed fuel vehicles is much greater than for gasoline-electric hybrids.
Keywords:	Fire, vehicles.
Comments:	Review of fire safety in vehicles.

Title:	**Driver perceptions of the safety implications of quiet electric vehicles.**
Published:	Cocron, P., & Krems, J. F. (2013). Accident Analysis & Prevention, 58: 122-131.
Link: **Free/priced:**	http://www.sciencedirect.com/science/article/pii/S0001457513001711 Priced
Objectives:	Two field studies in Germany examining the experiences and perceptions of low noise emission EVs.
Methodology:	Interviews and questionnaires were used with 70 participant drivers to gauge driver opinions before driving an EV for the first time and after three and six months of driving an EV.
Key Findings:	• Incidents related to low noise emission were rare, and typically occurred at low speeds. • Responses also revealed driver perception of risk due to low noise reduced with increasing driving experience, whilst the perception of driver comfort due to low noise increased over the 6-month driving period.
Keywords:	Electric vehicles, low noise, risk perception, traffic safety.
Comments:	

Title:	**Development of Nissan Approaching Vehicle Sound for Pedestrians.**
Published:	Tabata, T., Konet, H., & Kanuma, T. (2010). Nissan Motor.
Link: **Free/priced:**	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000097.pdf Paper Number 11- 0097, 2010 Free
Objectives:	To address concerns of low noise emission increasing risk for vulnerable road users, especially visually-impaired pedestrians, the approaching Vehicle Sound for Pedestrians (VSP) system has been developed by Nissan.
Methodology:	Discussion of the development of Nissan's Approaching Vehicle Sound for Pedestrians (VSP) system.
Key Findings:	• Designed for implementation in Nissan's first mass produced Electric Vehicle, the VSP emits one type of sound during forward motion, another type during 'take-off', when the vehicle first begins to move and a third type of sound for reverse motion. • The characteristics of the sound profile utilise knowledge of human ear sensitivity, age-related hearing loss, typical background noise conditions and visually-impaired pedestrian feedback and preferences gathered by surveys in Japan and USA.
Keywords:	Low noise vehicles, vulnerable road users, VSP, Nissan, EV.
Comments:	

Title:	**The impact of artificial vehicle sounds for pedestrians on driver stress.**
Published:	Cottrell, N. D., & Barton, B. K. (2012). Ergonomics, 55(12), 1476-1486.
Link: **Free/priced:**	http://www.tandfonline.com/doi/pdf/10.1080/00140139.2012.724452 Priced
Objectives:	The impact of adding synthetic sound to low noise emission vehicles on driver stress was investigated by the University of Idaho.
Methodology:	Through physiological measures (galvanic skin response and heart rate variance) and self-report questionnaires (Short Stress State Questionnaire – SSSQ) researchers examined driver stress whilst operating a Nissan HEV with one of three sound profiles: no added warning sound, manual addition of warning sound via vehicle horn, and automatic addition of warning sound via Nissan VSP system.
Key Findings:	The study found that the automated VSP system was preferred by drivers, causing less stress than when reliant on a manual warning for pedestrians via the vehicle horn.
Keywords:	Stress, automation, vehicle noise, driving task, task demand.
Comments:	

28 Calthorpe Road, Edgbaston, Birmingham, B15 1RP
Telephone: 0121 248 2000
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