Safe passenger cars

SWOV fact sheet, February 2022

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Summary

Since the seventies, the safety of car occupants has greatly improved, expressed in both the number of road crash fatalities and in mortality risk. Since 2011, however, the number of road deaths among car occupants has not decreased. The favourable developments in the last forty years are partly attributable to new/renewed safety features in cars and to legislation making (the use of) these safety features mandatory. Examples are seat belts, airbags and head restraints. Since 2000, car safety has improved by means of Electronic Stability Control (ESC) and Autonomous Emergency Braking (AEB). Not only the safety of car occupants has improved, but also that of other road users, such as cyclists and pedestrians. This is mainly due to a pedestrian-friendly car front, Autonomous Emergency Braking (AEB), and the Anti-lock Braking System (ABS). Further car safety improvement is to be expected when the development of safety systems and the execution of impact tests adequately reflect the entire population, taking into account diversity in measures and weights.

This fact sheet specifically concerns vehicle safety, not driver characteristics or behaviour, which is the subject of several other SWOV fact sheets. Information about intelligent vehicle safety systems can be found in SWOV fact sheet *Intelligent transport and advanced driver assistance systems (ITS and ADAS)*.

1 How many cars are there in the Netherlands and how many kilometres do they travel?

In 2019, 9.5 million cars with a Dutch registration number (for part of the year) were allowed onto public roads [1]. Of these, 8.3 million were registered in the name of private individuals and 1.2 million in the name of companies. In 2019, they travelled 82 billion and 22 billion kilometres respectively – together over 104 billion – on Dutch roads. Although the larger share of cars was registered in the name of private individuals, company-registered cars travelled about twice as many kilometres per vehicle (see *Table 1*).

Table 1. Number of cars (that had a Dutch registration number for at least part of 2019) and number of kilometres travelled in the Netherlands, by owner type.

Owner	Number of cars in 2019	Number of kilometres travelled in 2019* (x mln)	Average number of kilometres travelled in 2019
Private individual	8,328,873	82,046	9,851
Company	1,204,118	22,720	18,869
Total	9,532,991	104,766	10,990

** This concerns provisional figures for 2019. Source: Statistics Netherlands [1].*

2 How has the safety of car occupants evolved?

Since the seventies, the safety of car occupants has greatly improved, both expressed in the number of road deaths and in mortality risk. The blue line in *Figure 1* shows how many annual road deaths among car occupants were registered between 1950 and 2020.[1] From the fifties to the early seventies, the number of road deaths increased, peaking to 1358 in 1973. From 1976 to 2011 the number of road deaths decreased, while since 2011 the number of road deaths among car occupants no longer decreased. The red line in *Figure 1* shows how mortality risk developed between 1990 and 2020.[2] To measure mortality risk, we use the number of road deaths among occupants of Dutch and foreign cars per billion vehicle kilometres travelled in the Netherlands. Except for a peak in 1995, mortality risk decreased from 8.5 to 1.7 road deaths per billion kilometres between 1990 and 2014 and has, since then, increased to 2.3 road deaths per billion kilometres. Mortality risk was higher in 2020 than it had been in 2019.

1. The number of registered road deaths is lower than the actual number of road deaths. See also SWOV fact sheet *Road deaths in the Netherlands*.
2. At the time of the composition of this fact sheet, no numbers of vehicle kilometres travelled between 1950 and 1989 were known. Statistics Netherlands designates the number of vehicle kilometres travelled in 2018, 2019 and 2020 as 'provisional', which implies that mortality risk in 2018, 2019 en 2020 should also be considered 'provisional'.

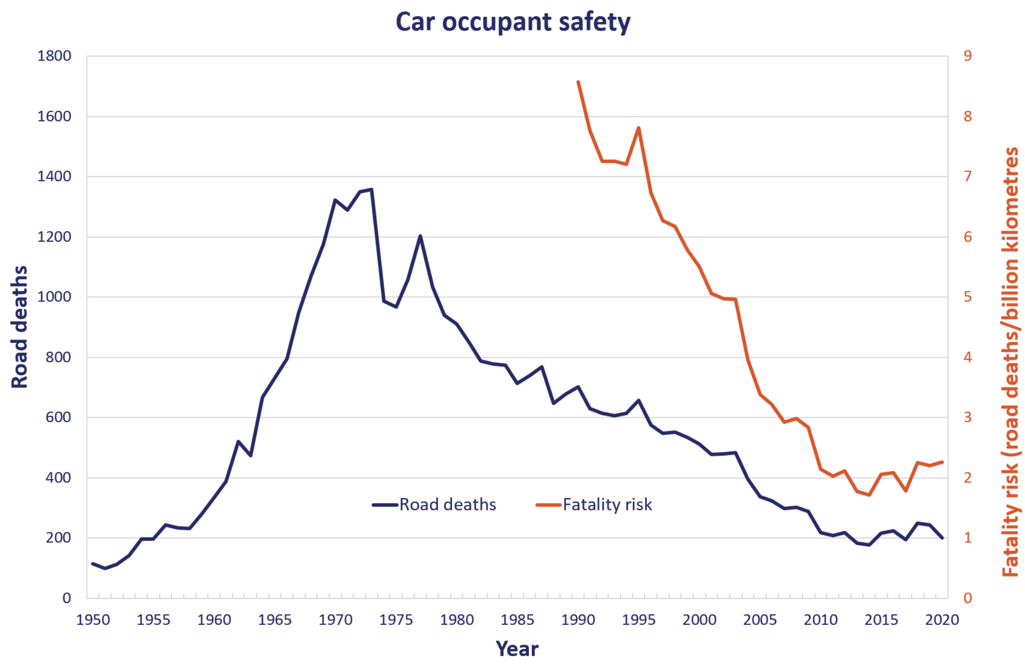

Figure 1. The number of registered road deaths among car occupants (1950-2020 period), and mortality risk defined as the number of registered road deaths among car occupants per billion kilometres travelled (1990-2020 period). The numbers for 2018, 2019 and 2020 are provisional numbers. (Sources road deaths: 1950-1975 Statistics Netherlands, 1976-2003 Crash registration VOR, 2004-present Police-registered road deaths (BRON), latest update using BRON-2020, dated August 2021; source vehicle kilometres travelled: Statistics Netherlands [2]).

3 What requirements do cars and drivers have to meet?

Cars

The *Regulation Vehicles* [3] describes three types of requirements that cars have to meet: approval requirements, permanent requirements, and usage requirements. The approval requirements are determined at European level per vehicle category [4] [5] and concern mass and size of vehicles, noise level, lighting, steering, braking system and occupant safety. Cars are admitted to the public road if they have obtained type-approval and have thus met the approval requirements. European member states are not allowed to apply stricter requirements for approval.

The permanent requirements refer to the technical condition of the vehicle and are periodically established during the *Periodic Technical Inspection* (Dutch abbreviation: *APK)* [6]. The European inspection requirements [7] are minimum requirements, member states are allowed to apply stricter standards. See the question *How does periodic technical inspection (PTI) of cars contribute to road safety?*

The usage requirements concern the way the car may be used. These include load transport (weight and size), towing of trailers and the driver's field of vision. Thus, objects or passengers may not obstruct the driver's view of the windshield and front side windows, and mirrors should be correctly adjusted. European member states determine the usage requirements themselves, but should comply with a number of preconditions [8]:

- because of possible (international) trade barriers, the rules should not be stretched so far as to prevent actual use of the vehicle on the road;
- the rules should be justifiable on account of legitimate government interests, among which road safety interests;
- the rules should be enforcable in practice.

In addition to these three requirement types, car manufacturers may voluntarily comply with Euro NCAP standards to improve safety and to distinguish themselves from other manufactures. See the question *How does Euro NCAP contribute to road safety?*

Drivers

Anyone using a car in traffic must have a driving licence. To qualify for a driving licence, candidates must at least be aged 17, be healthy, and have the knowledge and skills to enable safe, smooth and environmentally friendly traffic participation. Until drivers turn 18, they may only drive supervised by an experienced driver. For more information, see SWOV fact sheet *Driver training and driving tests*.

For older drivers, there is a test to determine their fitness to drive (age-related test). See SWOV fact sheet *Older road users*.

4 How has car safety improved over the years?

Since the first cars came onto the market at the start of the 20th century, numerous developments have improved occupant safety. These developments are partly due to new/renewed safety features in cars and to legislation making (the use of) these safety features mandatory. Thus, a Swedish study of road crashes in the 1994-2018 period shows that occupants of new cars (construction year 2014-2018) run a 67% smaller risk of serious injury (AIS3+) and a 58% smaller risk of a fatal crash outcome, compared to occupants of older cars (construction year 1980-1984) [9].[3] Using existing overviews [8] [10], some important safety features are described in terms of launching dates, mandation dates in the Netherlands, and their known road safety effects (see *Table 2*). It should be noted that many cars had already been equipped with safety features before they became mandatory (see the question *How does Euro NCAP contribute to road safety?*). The figures about the effect of the safety features cannot be used to estimate the total number of road casualties saved, because some safety features impact on the same crash type.

3. This study compares old and new cars in the current traffic context, which answers the question whether it is *now* safe to drive an old car. To answer the question whether a new car then was safer than a new car now, ideally crash risk of equally old cars is compared over different time periods (for example, using 1985 crash data of cars constructed in 1980 versus 2020 crash data of cars constructed in 2015).

Additional information about the safety features in *Table 2* can be found under the other questions in this fact sheet.

Table 2. Overview of safety features and their effect on occupant safety.

Safety features		Launch year*	Mandatory in the Netherlands since **	Current legislation ***	Effectiveness
Rigid occupant compartment/crumple zone		Years 40-1966	Not mandatory	Design may help meet UN/ECE 94 criteria (forces in a head-on collision), UN/ECE 95 (forces in a side collision)	No crash studies known about the safety effect of the crumple zone.
Seat belts	Three-point front seat belts	1959	1971 (presence) 1975 (mandatory usage)	UN/ECE 14,16,137, 145 (technical requirements), RVV 1990 (mandatory usage)	Risk of fatal crash or serious injuries: -60% [11].
	Three-point rear seat belts	1972	1990 (presence) 1992 (mandatory usage)		Risk of fatal crash or serious injuries: -44% [11].
Head restraints		1968	1999 (front)	UN/ECE 17 UN/ECE 25	No crash studies known about the safety effect of head restraints.
Anti-lock Braking System (ABS)		1971	Not mandatory	UN/ECE 13H (if present)	Risk of single-vehicle crash (among which rolling over or colliding with a fixed object): +14% to +22%. Risk of crash with pedestrians, cyclists or animals: -27%. Risk of crash with turning vehicles: -8%. Risk of injury: -1%. Risk of fatal crash: +6% [12].
Child seat		1972	1977	Guideline 2003/20/EG	Risk of serious injury during usage: -28% to -81% [13] [14]. Crash studies do not show an unequivocal effect of using booster seats [15].
Airbags	Driver (front airbag)	1980	Not mandatory, but front airbags for driver and passenger are actually included in the standard equipment	UN/ECE 94 (information about the presence of airbags) UN/ECE 114 (technical requirements of replacement airbag systems) Airbags may contribute to meeting the UN/ECE 135 criteria [16]	Risk of fatal crash when seat belts are present: -11% (aggregated for all crash types) up to -22% (for head-on crashes in particular) [17] [18].
	Side airbags	1994			Risk of fatal crash or serious injury at a side collision on the driver's side in case of side airbags combined with curtain airbags: -41% (aggregated for all body parts) up to -48% (particularly for head, neck, face, breast and abdomen) [19].
	Curtain airbags	1998			
Electronic Stability Control (ESC) ****		1996	2014	EC 661/2009 UN/ECE 140	Risk of fatal single-vehicle crash: -30% to -50% for regular cars, -50 to -70% for SUVs [20]. Risk of fatal outcome of rollover: -70 to -90% [20].
Autonomous Emergency Braking (AEB)		2000	2024	EC 2019/2144	Risk of rear-end collision: -38% [21] to -43% [22]. Risk of a rear-end collision resulting in injuries: -45% [22].

** Date of market launch adopted from Van Kampen et al. [8], excepting ABS [23].*

*** Sources of mandation dates for new cars: seat belts and mandatory usage in front [8], rear seat belts (Art. 5.2.47 (2) in: [3], mandatory usage seat belts in the rear (Art. 1 in: [24], head restraints (Art. 2 in: [25], child seats [8], ESC (Art 13 (5) in [26], AEB (Appendix 2 (C9) in: [5]). The mandation date of safety features for type approval of new car models is usually two years prior to mandation of safety features for new cars.*

**** UN/ECE guidelines are available in [27].*

***** ESC was originally introduced as 'electronic stability programme' (ESP).*

5 How has improved car safety benefited other road users?

Throughout the years, improved car safety has also benefited other road users; the risk of a car crashing with cyclists or pedestrians has decreased, as has the risk of a serious outcome of such a crash. *Table 3* presents a summary of some important safety feature characteristics: date of market launch, mandation in the Netherlands, and what is known about the road safety effect. Bear in mind that a lot of cars had already been equipped with safety features before they became mandatory (see the question *How does Euro NCAP contribute to road safety?*). The effectiveness figures cannot be used to estimate the total number of road casualties saved, because some safety features impact on the same crash type. For additional information about the safety features in *Table 3*, see the other questions in this fact sheet.

Table 3. Overview of safety features and their effect on the road safety of other road users

Safety feature		Launch year*	Mandatory in the Netherlands since **	Current legislation ***	Effectiveness
Anti-lock braking System (ABS)		1971	Not mandatory	UN/ECE 13H (if present)	Risk of crashes with pedestrians, cyclists or animals: -27%. No known data about the severity of the crashes [12] [28] [29].
AEB for pedestrians and cyclists		Unknown	2026	EC 2019/2144	No crash studies known about the safety effect of pedestrian or cyclist AEBs.
Pedestrian-friendly car front	Pop-up hood	2006	Not mandatory, but tested by Euro NCAP [30]	Design may help meet head impact criteria, UN/ECE 127	No crash studies known about the safety effect of a pop-up hood.
	Pedestrian airbag	2012		Not applicable	No crash studies known about the safety effect of a pedestrian airbag.
Acoustic Vehicle Alerting System (AVAS) for audibility of silent electric vehicles at low speeds		2011	2021 [31]	EC 540/2014, UN/ECE 138	No crash studies known about the safety effect of AVAS.

** Dates of market launch: ABS [23], AEB [8], pop-up hood [32], pedestrian airbag [33], AVAS [34]. The date of the market launch of an AEB for pedestrians and cyclists could not be ascertained.*

*** Mandation dates for new cars: AEB [35], AVAS [31].*

**** UN/ECE guidelines are available in [27].*

6 How old is the Dutch car fleet?

The age distribution of cars on 1 January 2020 can be found in *Figure 2*. It shows that it takes an average of ten years before at least half the car fleet is equipped with a new or renewed safety feature. On the reference date of 1 January 2020, for example, at least 36% of cars were equipped with electronic stability control, which had become mandatory in 2014.

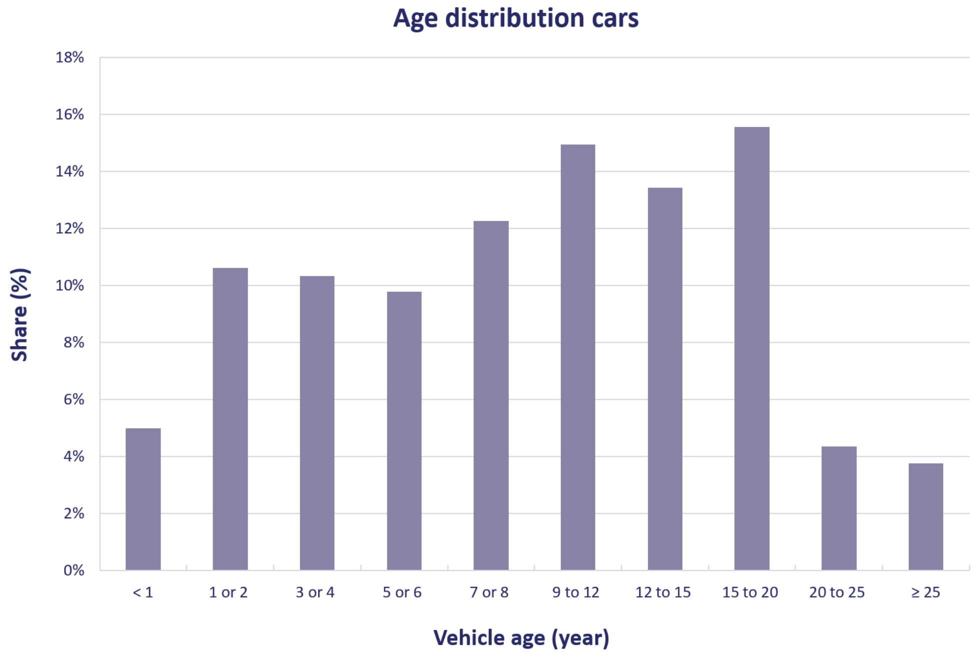

Figure 2. Age distribution of Dutch cars on 1 January 2020. At this point in time, the total number of Dutch cars amounted to 8,677,911. Source: Statistics Netherlands/Netherlands Vehicle Authority [36].

7 How safe are SUVs?

A Sports Utility Vehicle (SUV) is a relatively large and heavy car, with higher ground clearance than regular cars. As early as 2005, Van Kampen et al. [8] described a steady increase in mass differences between cars, particularly between the compact class and the SUV class. When two vehicles of different masses collide, the lighter vehicle takes a bigger hit than the heavier vehicle.

This principle is illustrated by crash studies, that show that the fatality risk for occupants of regular cars is significantly higher when crashing with an SUV, whereas the fatality risk for SUV occupants is significantly lower [37] [38]. SUVs are therefore safe for their occupants, but present an increased risk to other traffic. However, the American crash study by Monfort and Nolan [38] notes that in fatal crashes between regular cars and SUVs, mass differences decreased between 1989 and 2016. We do not know to what extent this decrease also applies to Europe where, on average, regular cars are lighter than in America [39].

The position of SUV bumpers is usually higher than it is for regular cars, which implies that in a collision between these vehicle types, the impact energy is not absorbed to an optimum degree and the smaller car risks sliding under the SUV [40]. In America, the car industry introduced a standard to lower the energy-absorbing structure behind the SUV bumper to the same height as is common for regular cars. There is no consensus about the safety effect of this voluntary measure. Studying American crashes between SUVs and regular cars, Baker et al. [41] found that the fatality risk for drivers of regular cars decreased when the height of the energy-absorbing structure of the two vehicle types no longer differed. Again on the basis of crashes, Ossiander et al. [42], however, found no effect of lower SUV bumpers. Contrary to the study by Baker et al. [41], they not only corrected for the effects of seat belt usage and vehicle mass, but also for other factors, such as road type, speed limit, and driver characteristics.

No crash studies are known comparing the (un)safety of SUVs to regular cars for vulnerable road users such as pedestrians and cyclists.

8 How safe are electric cars?

Three factors may make electric cars less safe than cars with a combustion engine: lower sound intensity, risk of fire because of the battery, and a higher weight.

Lower sound intensity

Sound – particularly for cyclists and pedestrians – is an important factor in noticing other road users that are outside one's field of vision or that are less visible due to fog and darkness [43] [44] [45]. A literature survey shows that electric vehicles are more silent than cars with a combustion engine at speeds up to 20 or 30 km/h [46]. Above this speed, no differences in sound intensity were found, probably because the tyres made more noise than the engine.

Since 1 July 2021, all new hybrid and fully electric vehicles in the European Union have had to be fitted with an *Acoustic Vehicle Alerting System* (AVAS), or artificially added sound at a forward speed up to 20 km/h and when reversing [47]. A field study illustrates that AVAS makes silent electric vehicles more noticeable to cyclists and pedestrians [48]. Yet, the EU guideline warrants some comment: it does not prescribe what the alerts should actually sound like, which allows car manufacturers some design scope and offers drivers different options, although this could imply that other road users may fail to recognise the sound [49] [50].

Risk of fire because of battery

Crash figures do not allow us to determine whether fire was the cause of a road crash injury. Nevertheless, compared to cars with a combustion engine, the batteries of electric cars increase the risk of fire. In extreme heat or cold, even though rare in the Netherlands, the risk of the battery catching fire increases [51]. In addition, in a crash in which large speed differences are a factor, the battery may get damaged and thus catch fire [51].

Extinguishing the fire is also different for electric cars compared to cars with a combustion engine. Since the extinguishing agents cannot reach the inside of the battery, it may re-ignite even days after the crash, unless it is sufficiently cooled (NTSC, 2018 in Sun et al. [51]). Therefore electric cars pose an additional danger to those having to extinguish the fire, or move, store or examine the vehicle.

Higher weight of electric cars

In a crash, a vehicle with a greater mass will cause severer injuries for the crash opponent than a vehicle with a smaller mass [52]. *Figure 3* shows the average mass of cars involved in a fatal crash or serious-injury crash in 2009-2019[4] for three types of fuel. This shows that, during this period, the average mass of (hybrid) electric cars increased and that between 2014 and 2019 their average mass exceeded that of cars running on petrol or diesel. On the basis of a study by Berends [52], and if the trend in *Figure 3* continues, we may assume that the average outcome of crashes will be more severe in crashes involving a relatively new electric vehicle.

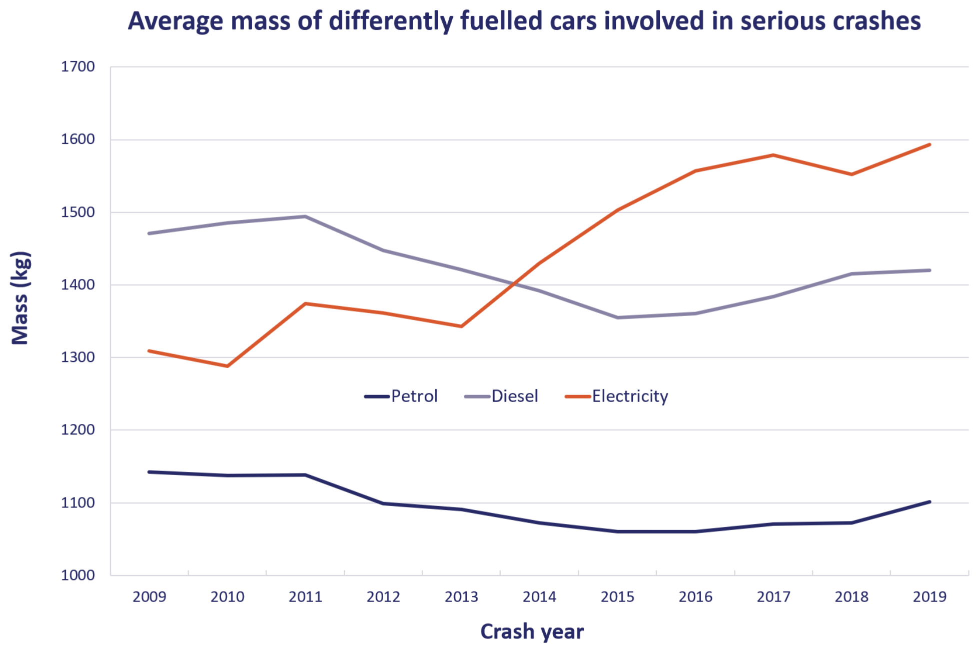

Figure 3. Average mass of cars involved in fatal crashes and injury crashes in 2009-2014, irrespective of crash opponent.[4] *Hybrid vehicles are included in the 'electricity' category. Source: BRON.*

4. To allow comparison of cars with different energy sources, we only look at cars that were less than 6 years old at the time of the crash. This reduces the risk of comparing vehicles with and without (advanced) vehicle safety systems. Crashes of cars that were powered by LPG, natural gas, or alcohol were left out because of the few crash-involved cars using these fuel types.

9 What is the safety effect of a safety cage or crumple zone?

A safety cage, which hardly deforms in a crash, is a rigid construction to protect car occupants. Front and rear crumple zones diminish the g-forces transferred to the bodies of the car occupants in a head-on crash or rear-end collision. This is achieved by the deformation of the crumple zones, which absorb the kinetic energy released in a crash. There are no known crash studies that prove safety cages and crumple zones affect occupant safety. Since cars have had this combined safety feature for decades, it is unlikely that a comparative crash study of cars with and without the combined feature is feasible. What can be noted, however, is that the quality of the cage construction and crumple zone has improved over the years, for example by using better materials. This may have contributed to the improved safety of new cars compared to older ones [9].

For vehicle admission, the combination of a safety cage and a crumple zone is not mandatory. However, their use may contribute to meeting the requirements of the UN/ECE guidelines 94 and 95 [27], which specify the maximum extent of the forces a vehicle may exert on an occupant during a crash test consisting of a head-on crash and a side collision.

10 What is the safety effect of seat belts?

Assessment of thirty international studies shows that using a three-point seat belt reduces the risk of a fatal outcome or serious injury after a crash by about 60% for the occupants in front and by about 44% for the occupants in the rear of the vehicle [11]. In terms of specific injury, a different assessment of 11 studies found that wearing a seat belt resulted in fewer injuries to the face, abdomen and back. No significant effects were found for reduced injuries to the head, neck, limbs, and breast region.

A seat belt appears to offer better protection to middle-aged men than to older occupants (65+) [54] or to women [54] [55]. A reason might be that seat belts are tested with a dummy shaped like an adult male [56] [57]. Compared to an adult male, older people have relatively brittle bones for example, which increases the risk of broken ribs due to the impact of the seat belt in a crash [58]. Crash studies explain the difference in injury severity between men and women, when both wear seat belts, by pointing out that women’s necks are usually thinner and their neck muscles less strong [54] [55]. In a crash, the seat belt keeps the body in a fixed position, but not the head. Together with a head restraint that is not in an optimal position (for, also tested on a dummy shaped like an adult male) this increases risk of whiplash-related injuries.

On 1 January 1971, attachment points and front seat belts became mandatory. On 1 June 1975, seat belt usage for the front seats became mandatory and on 1 April 1992 for the rear seats as well. In a 2010 sample, 97% of the car occupants in the front seats wore a seat belt, and about 82% of those seated in the rear [59]. In 2020, a similar sample found 99% of car occupants wore seat belts without distinguishing between front and rear seats [60]. In fatal crashes, occupants were proven to have worn seat belts less often; on Dutch national roads, a quarter to a third of the deceased occupants had not worn seat belts. Over half of them were completely or partly ejected from the vehicle [61] [62].

The safety effect of seat belts is greatest when they are worn correctly, namely fitting snugly across the body [63]. When a seat belt has too much free play, a collision will increase the pressure on the body, which may result in broken ribs or a broken sternum. Therefore, occupants should not wear thick coats, nor should they carry things in their pockets that could be pressed into their bodies. If the belt has too much free play, the occupant may slide under the seat belt, which will result in internal injury to the abdomen due to the hip belt, and injury to the legs due to contact with the rigid parts of the car. The diagonal part or shoulder part should not be too close to the neck, but should fit diagonally across the middle of the shoulder and the middle of the sternum. To achieve optimum fixation of the shoulder, cars often have an adjustable upper anchor point that users can adjust themselves, depending on the length of their upper bodies and the chair position. The hip region of the belt should be as low as possible, and should not touch the abdomen to prevent organ injury, which is especially important for pregnant women [64].

11 What is the safety effect of airbags?

For vehicle occupants, common airbags are front airbags, side airbags, curtain airbags, belt airbags and knee airbags. Each airbag type has been developed to prevent a specific type of injury, often related to particular crash types. In practice, most airbag categories significantly improve occupant safety, particularly in combination with seat belt usage. However, some undesired side effects have come to light.

Positive effects

Front airbags are effective when occupants wear seat belts and thus serve as a useful addition. An assessment of 22 international crash studies reports a 15% decrease in fatal crashes when front airbags are combined with seat belt usage by the driver. In crashes in which the driver did not wear a seat belt, no significant effect of front airbags was found on the prevention of fatal injuries [18]. Door airbags or airbags on the outer sides of the chairs (side airbags) and in the roof edge (curtain airbags) play an important role when the car is hit from the side or when it hits a tree or other vertical object sideways. For cars with both side and curtain airbags, an Australian crash study found the risk of a fatal outcome or injuries to the head, neck, face, breast and abdomen to be 48% lower [19]. For cars with only side airbags, no significant safety effect was found. Knee airbags are located underneath the steering wheel (for the driver) or underneath the glove compartment (for a passenger in front) and are intended to prevent injuries to the knees, femurs, and hips in case of a front-end crash. A crash study shows a significant safety improvement in AIS2+ knee and hip injuries [65]. Finally, belt airbags protect rear passengers due to a cold gas reservoir installed in the seat belts. These so-called inflatable belt airbags at least cover a five times higher body surface than regular seat belts, so that the forces exerted on the passenger's body can be absorbed, belt injuries are diminished or prevented and the passenger is better held in place. Studies quantifying the safety effect of belt airbags are not available yet.

Undesired side effects

In addition to positive safety effects, several studies have also reported undesired side effects of airbags, for example when babies are transported on the passenger seat. If the airbag is activated, a head-on crash may be fatal for the child, because the airbag forcefully throws the child seat backwards along with the child. Therefore a back-facing child seat is only to be placed on a chair if the airbag has been de-activated. Moreover, warning stickers in front are mandatory for cars with one or more airbags at the front passenger seat. The first generation of front airbags heightened the risk of brain and neck injury for children, small women, and occupants that were not seated in the driving direction at the time of the crash [66]. After guidelines had been introduced to limit the force with which front airbags unfold, the United States saw a decrease in fatalities due to front airbags [67]. On the basis of an in-depth study and crash test, Hallman et al. [66] show that side airbags, situated at the height of the spleen, can result in spleen injury when they unfold. Funk et al. [68] describe an undesired side effect of curtain airbags: although the risk of the driver being ejected through the side window appears to decrease, for cars with roof windows the risk of the driver being ejected through the roof window instead appears to be higher.

12 What is the safety effect of head restraints?

Head restraints are intended to prevent or reduce neck injuries (such as whiplash) in head-on crashes. An American study based on insurance data shows that cars in which seats and head restraints could properly be fitted to the body length of the front passenger, the risk of neck injuries was 11% lower than it was for cars in which this customisation was not possible [69]. On the basis of personal injury claims, no conclusion about injury severity may be drawn.

The top of the head restraint should at least end above the ear to prevent or reduce neck injury. The horizontal distance between the head and the head restraint should be as small as possible, but definitely not greater than ten centimetres [70]. Depending on body length, these criteria can be met by properly adjusting the chair angle and the angle and height of the head restraint, if the restraint is adjustable. In a sample of over 1,000 front occupants, the head restraint was adjusted to the proper minimum height for 26% of the drivers and 48% of the passengers [70]. An American observation study found that, in order to reduce neck injuries, the head restraint was at the required minimum height for only 10% of the drivers [71]. On the basis of crash tests with dummies, Viano and Gargan [71] estimate that a suboptimal height of the head restraint more than triples the risk of neck injuries compared to head restraints at an optimal height.

For new cars in Europe, front head restraints have been mandatory since 1997. If rear head restraints are present, they have to meet the requirements of the UN/ECE vehicle guidelines 17 and 25.

13 What is the safety effect of winter tyres?

There is no clear evidence for a safety effect of winter tyres. It has been suggested that, from 7 degrees Celsius (and below) winter tyres are safer than summer tyres: winter tyres are alleged to improve grip and shorten braking distance. There are, however, hardly any crash studies comparing the road safety effect of winter tyres to that of summer tyres. The crash studies that do exist, are limited to comparing winter tyres with and without metal studs. Moreover, these studies use crash figures from countries such as Sweden [72] and Finland [73], where winter conditions are unlike those in the Netherlands.

Tyre tests do not offer a clear picture either. They usually compare tyres of different brands but meant for the same weather conditions (see, for example the summer and winter tyre tests of the Dutch ANWB). An exception is the 2009 tyre test of TSC (the Swiss sister organisation of ANWB) [74], which compared summer, winter and all-season tyres in different weather conditions. The results (see *Table 4*) showed that the differences between snowy and dry roads were particularly evident: on snowy roads, the braking distance of winter tyres was clearly shorter than that of summer tyres, whereas on dry roads this was the other way around. On wet roads, the performance depended on temperatures and the differences were smaller. Yet, the results should be interpreted with caution. It is, for example, unclear how the tests were carried out and if the tested tyres had the same quality. Moreover, it is hard to translate the results to the Dutch situation, because there hardly tends to be any snow in the Netherlands. To allow for an estimation of the road safety effect of winter tyres, more research is therefore required.

Winter tyres are not mandatory in the Netherlands. In other countries, like Germany, they are mandatory for some parts of the year, in some weather conditions, and/or on some roads. More information about the rules abroad can be found on the ANWB website [75].

Table 4. Performance of summer, winter and all-season tyres in different weather conditions [in adjusted form adopted from [74])

Test criteria	Test conditions	Summer tyres	Winter tyres	All-season tyres
Braking distance dry	100 – 0 km/h	38 m	51 m	49 m
	About 10°C	38 m	56 m	52 m
Braking distance wet	100 – 0 km/h	43 m	40 m	44 m
	Ca. 20 – 25°C	40 m	45 m	47 m
Braking distance snowy	80 – 0 km/h	61 m	29 m	42 m
Fuel consumption	About 10°C	7.5	7.6	7.9
Wear	80 – 0 km/h	105%	100%	115%
	About 20 – 25°C	100%	115%	110%

14 What is the safety effect of an anti-lock braking system (ABS)?

An anti-lock braking system (ABS) prevents the wheels from locking, which results in a more stable road handling and manoeuvrability. Crash study reviews [12] [76] show that the presence of ABS goes hand in hand with a significant decrease in multiple crashes on wet or poor road surfaces, crashes with turning vehicles, and crashes with pedestrians, cyclists and animals. However, the presence of ABS also goes hand in hand with a significant increase in single-vehicle crashes (among which rolling over and colliding with a fixed obstacle). According to Elvik et al. [12], who looked at crash outcome, the net effect of ABS on road safety is a decrease in injury crashes (-1%), but also an increase in fatal injury crashes (+6%).

The increase in single-vehicle crashes due to ABS has not yet been conclusively explained. Burton et al. [29] mention two principles that may be at play: behavioural adaptation and excessive steering to prevent a crash. A German crash study, for example, found an indication of behavioural adaptation: drivers of cars with ABS drove faster and more aggressively [77]. Based on speed measurements in daily traffic, however, an American study did not find higher driving speeds for vehicles with ABS [78]. If braking is accompanied by excessive steering, the vehicle runs the risk of rolling over due to the extra grip because of ABS. This risk seems to be reduced by the introduction of electronic stability control (ESC); a system that builds upon ABS (see the question *What is the road safety effect of electronic stability control (ESC)?*).

For cars in Europe, ABS is not mandatory. Yet, once it has been implemented, the European vehicle guidelines in UN/ECE 13H apply. Partly thanks to the development and mandation of electronic stability control (ESC), which uses ABS technology, ABS has indirectly become mandatory for new cars too.

15 What is the safety effect of electronic stability control (ESC)?

Electronic stability control (ESC) is a safety feature to stabilise the car and keep it on its course while preventing skidding. ESC compares steering movements to the actual course of the car. If the movements deviate, for example during skidding, ESC can brake individual wheels. This will prevent skidding or over- or understeering in curves taken at high speeds, losing control and ending up in the verge. Landing in the verge may cause the vehicle to roll over. Because verge landings are prevented, rollovers are prevented as well and subsequent injuries for the car occupants. An assessment of 15 international studies shows that the risk of a fatal outcome of a single-vehicle crash is 30% to 50% lower for regular cars with ESC than for regular cars without ESC. For SUVs, the risk of a fatal outcome is 50% to 70% lower. The risk of a fatal outcome of a rollover is 70% to 90% lower, irrespective of the car type [20]. Assessing eight international studies, Erke [79] found that the presence of ESC goes hand in hand with a decrease of single-vehicle crashes (-49%), head-on crashes (-13%), and fatal crashes with more than two crash opponents (-32%).

Since 2014, ESC has been mandatory for new cars in Europe, in compliance with the EC 661/2009 guideline [26]. Chistoph [80] estimates that, on account of mandation, ESC had a penetration rate of 57% for Dutch cars in 2020, which will have increased to 78% in 2030.

16 What is the safety effect of child seats?

For children, the use of child protection equipment[5] decreases the risk of serious or fatal injuries. The safety benefits do, however, strongly differ per study, target group and type of equipment. For children aged 1-4, Arbogast et al. [81] found a 78% lower risk of serious injuries when child protection equipment (irrespective of type) was used as opposed to just regular seat belts. For child seats in particular, Zaloshnja, Miller & Hendrie [14] found an 81% lower risk of serious injury for crash-involved children aged 2-3. Elliot et al. [13] show a 28% lower risk of a fatal outcome for children aged 2-6.

For children having outgrown child seats, there are booster seats. They ensure that the shoulder part of the three-point seat belt fits over the child's shoulder properly and, more importantly, that the hip part runs over the pelvis and not the abdomen, where it may damage the soft tissue in the abdominal cavity [82]. An assessment of 11 international studies based on crash figures shows that the effect of a booster seat in addition to a seat belt varies [15]. In some studies, booster seats were associated with a significant reduction in serious injuries, while other studies did not find any significant effect on the number of fatalities or serious injuries. In only one study, booster seats were associated with an increase of serious injuries.

In 2003, a European guideline[6] dictated that for children shorter than 1 m 35 or 1 m 50 child protection equipment should be used, both in the front and the back of the car. Whether a height of 1 m 35 (e.g. the Netherlands) or 1 m 50 (e.g. Germany) should be chosen, is left up to the member states. Research by VeiligheidNL (in 2018) among 470 children aged 0-8 showed that 83% of the children were not transported correctly; i.e. they were not properly secured in child seats or were not even *in* a child seat while being shorter than 1 m 35 [83]. Of the child seats used, 7% were either too big or too small and 49% were not correctly fastened. 59% of the children were not correctly secured in the child seats. If children are not correctly secured, this may reduce the effectiveness of child seats and, thus, lead to an increased injury risk in crashes [13] [84] [85] [86]. A Belgian study, for example, showed that for one third of the children who were secured with protection equipment, the improper use of the seats seriously reduced or annihilated their effectiveness [84].

5. We have chosen the umbrella term ' child protection equipment', subdivided into baby seats, child seats and booster seats. Other government or manufacturer publications use different umbrella terms, such as ' child safety systems', 'child seats', ' car seats' or ' car child seats', while also using different terms for subgroups. It is usually obvious what is meant, even more so if the target group is mentioned.
6. Guideline 2003/20/EU, amending guideline 91/671/EEU, effective from 1 March 2006.

17 What is the safety effect of a pedestrian-friendly car front?

The effects of a pedestrian-friendly car front in terms of crashes and injury severity are unknown, but simulation studies and crash tests result in estimates that a pop-up hood and pedestrian/cyclist airbags may achieve significant safety gains.

For pedestrians and cyclists, the head is one of the body parts that is most vulnerable in case of a head-on crash with a car. A pop-up hood ('Active Hood Lifting System') is needed if the vehicle design does not allow enough deformation space to be created between the hood and the rigid parts underneath. A pop-up hood will lift about 10 centimetres as soon as a head-on crash with a pedestrian is registered (usually with the legs). By the time the pedestrian's head makes contact with the lifted hood, the impact will be smaller. Because the hood now has room for further indentation, a larger part of the kinetic energy is absorbed than if the hood was flush with the rigid engine block. A simulation study of 101 fatal pedestrian-car crashes resulted in a reduction of 33-84 fatalities if the car had a pop-up hood [87].

Pedestrian airbags may also protect a pedestrian's head against the consequences of a crash with the A styles, the roof edge or the windscreen of a car. A series of crash tests, based on 68 pedestrian-car crashes involving serious head injuries, showed that the risk of these injuries decreased by 31% to 94% [88]. Effectiveness depended on airbag type, crash speed and which part of the car hit the pedestrian's head. A simulation study suggests that pedestrian airbags may also protect the heads of cyclists, reporting a 75% lower maximum impact force on the head of the virtual cyclist [89]. A condition is that the 'cyclist airbag system' will recognise cyclists and that it can be positioned in such a way as to also protect cyclists whose heads will hit a different part of the hood than is the case with pedestrians.

The pop-up hood and pedestrian airbag are not mandatory, but they may contribute to meeting the criteria for head impact as described in UN/ECE guideline 127 [90], and they may be taken into account in the safety assessments in Euro NCAP tests. This may encourage car manufactures to integrate such systems into their cars (see the question *How does Euro NCAP contribute to road safety?*).

18 How does periodic technical inspection (PTI) of cars contribute to road safety?

PTI is meant to reduce the share of cars that are driving around with technical defects, and thus to reduce the number of crashes caused by them. Not much is known about the road safety effect of PTI. Although there are estimates of the share of crashes involving cars with technical defects (0,5 tot 24%; [91]), the effect of PTI has not yet been studied.

During PTI, the technical condition of the car is inspected. The focus of the inspection is on safety aspects, such as the proper functioning of the vehicle lighting, brakes, steering, and tyres [6]. In addition, checks are done to see if pollution by exhaust gases is within limits. More information about the car parts that have to be checked is to be found in the digital PTI handbook (APK-handboek voor personenauto's).

In the Netherlands, the fuel type determines when a car needs a PTI. Cars that use petrol, alcohol or electricity need their first PTI four years after their admission date. The next two PTIs are every two years. After eight years, cars need an annual PTI (4-2-2-1 scheme). Cars that (partly) use a different fuel need a PTI after the first three years, followed by annual PTIs (3-1-1 scheme). Cars that are 30 to 50 years old need biennial PTIs (2-2-2 scheme) [92]. Since 2021, cars that are 50 years old or older have been exempted from PTI mandation [93].

19 How does Euro NCAP contribute to road safety?

The *European New Car Assessment Programme* (Euro NCAP) intends to clarify car safety for both consumers and manufacturers. Since 1997, this has implied that most common new car models undergo several tests, the results of which are expressed in a rating of 0 to 5 stars: the more stars, the safer the car. Cars that merely meet the approval requirements (see the question *What requirements do cars and their drivers have to meet?*) do not receive any stars. The test results are available to anyone; this may encourage manufacturers to produce safer cars.

The Euro NCAP assessment system distinguishes between car classes, such as large or small family cars, and superminis. Cars are compared within classes. Since 2009, the assessment system has been subdivided into four categories: adult occupants, child occupants, vulnerable road users and safety assist. Each category contains different assessment criteria (see *Table 5*). They are regularly adjusted to the latest insights and regulations. Electronic stability control is, for example, no longer tested for, because this has been mandatory for new cars since 2014, and in 2020 *rescuing and freeing* have been added.

Table 5. Assessment criteria Euro NCAP (January 2021).

Adult occupant	Child occupant	Vulnerable road user	Safety assist
› Frontal impact › Lateral impact › Rear impact › Rescue and extrication	› Child restraint system (CRS) performance (in a front-end crash or side collision) › Vehicle provisions › CRS installation check	› Head impact › Upper leg impact › Lower leg impact › AEB pedestrian › AEB cyclist	› AEB car-to-car › Occupant status monitoring › Speed assistance › Lane support

Several studies have found correlations between Euro NCAP ratings (0 to 5 stars) and injury risk for car occupants. The analysis of car-car crashes showed that there were fewer fatal or severe injuries for cars with multiple stars than for cars with only few stars [9] [94] [95]. In addition, analyses of car-pedestrian crashes showed a correlation between the Euro NCAP pedestrian ratings (which nowadays extend to consequences for vulnerable road users) and pedestrian injury risk. Here again, cars with higher ratings perform better [96] [97].

The net safety effect of Euro NCAP is, however, hard to quantify. This is because there are hardly any data about the distribution of Euro NCAP ratings across the European or Dutch car fleet. Although an ever larger part of tested cars get high ratings, in 2013 the share of new cars with 5 star ratings only amounted to 2.5% of the European car fleet and 3% of the Dutch car fleet [98]. Moreover, in the last few decades all cars have become safer and ratings of cars of different classes cannot be compared.

20 What other measures may improve car safety?

Measures to further increase car safety mainly relate to Advanced Driver Assistance Systems (ADAS) and intelligent transport systems (ITS), such as Intelligent Speed Adaptation (ISA), (Cooperative) Adaptive Cruise Control (C-ACC) and Lane Departure Warning (LDW) (see SWOV fact sheet *Intelligent transport and advanced driver assistance systems (ITS and ADAS)*).

In 2018, The European Commission proposed mandation of new safety systems, such as intelligent speed assistance (ISA), and support for an alcolock [99]. These safety proposals are as yet rather noncommittal. Support for an alcolock, for example, does not guarantee that alcolocks will be implemented more often. Mandation of alcolocks is left to the member states, and in the Netherlands other measures are preferred ([100]; see fact sheet *Driving under the influence of alcohol*). The technical requirements of the ISA proposed by the EC are still being debated [101]. Presently, consensus tends towards an informing ISA as a minimum requirement: drivers will be alerted when they exceed maximum speeds. This ISA version is significantly less effective than an intervening version (see fact sheet *Speed and speed management*). For the purpose of road safety, introduction of an intervening version would have most impact; possibly locally: for example in 30 km/h areas or near schools.

Safety gains could also be realised by means of car design. Crash test dummies usually represent the average adult male, which implies that seat belts and air bags are not tailored to other population groups. There are indications that people who differ from the average adult male in age, weight or gender run a higher risk of severe or fatal injuries [102]. In the VIRTUAL project, more diverse 'open source human body models' are being developed at EU level. Such models would improve evaluation of the extent to which safety features in cars can be tailored to different occupants.

Finally, the government could consider to encourage the purchase of safer cars by means of tax benefits [103]. Currently, the Dutch government, for instance, encourages the purchase of clean and energy-efficient cars. A similar programme for cars with better safety features could improve road safety. Yet, considering the average age of the Dutch car fleet (see the question *How old is the Dutch car fleet?*), it will take years before a large share will be equipped with safety features. To accelerate safety gains from these features, encouraging retro-fits (implementing systems into existing vehicles) could be considered.

Publications and sources

Below you will find the list of references that are used in this fact sheet; all sources can be consulted or retrieved. Via Publications you can find more literature on the subject of road safety.

[1]. CBS Statline (2020). *Verkeersprestaties personenauto's; kilometers, brandstofsoort, grondgebied*. CBS. Accessed on 28-06-2021 at https://opendata.cbs.nl/#/CBS/nl/dataset/80428ned/table?dl=4656F.

[2]. CBS (2020). *Verkeersprestaties motorvoertuigen; kilometers, voertuigsoort, grondgebied*. CBS. Accessed on 19-11-2020 at https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80302ned/table?fromstatweb.

[3]. Overheid.nl (2021). *Regeling voertuigen. Regeling tot uitvoering de hoofdstukken III en VI van de Wegenverkeerswet 1994 (Regeling voertuigen)*. De Minister van Verkeer en Waterstaat. Accessed on 18-08-2021 at https://wetten.overheid.nl/BWBR0025798/2021-01-21.

[4]. European Parliament (2018). *Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC (Text with EEA relevance.)*. Document 32018R0858. Official Journal of the European Union, Brussels.

[5]. European Parliament (2019). *Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018/858 of the European Parliament and of the Council and repealing Regulations (EC) No 78/2009, (EC) No 79/2009 and (EC) No 661/2009 of the European Parliament and of the Council and Commission Regulations (EC) No 631/2009, (EU) No 406/2010, (EU) No 672/2010, (EU) No 1003/2010, (EU) No 1005/2010, (EU) No 1008/2010, (EU) No 1009/2010, (EU) No 19/2011, (EU) No 109/2011, (EU) No 458/2011, (EU) No 65/2012, (EU) No 130/2012, (EU) No 347/2012, (EU) No 351/2012, (EU) No 1230/2012 and (EU) 2015/166 (Text with EEA relevance)*. Document 32019R2144. Official Journal of the European Union, Brussels.

[6]. RDW (2021). *APK*. RDW. Accessed on 11-06-2021 at https://www.rdw.nl/particulier/voertuigen/auto/apk.

[7]. European Parliament (2014). *Directive 2014/45/EU of the European Parliament and of the Council of 3 April 2014 on periodic roadworthiness tests for motor vehicles and their trailers and repealing Directive 2009/40/EC Text with EEA relevance*. Document 32014L0045. Official Journal of the European Union, Brussels.

[8]. Kampen, B. van, Krop, W. & Schoon, C. (2005). *Auto's om veilig mee huis te komen*. SWOV & RAI Vereniging, Leidschendam.

[9]. Kullgren, A., Axelsson, A., Stigson, H. & Ydenius, A. (2019). *Developments in car crash safety and comparisons between results from EuroNCAP tests and real-world crashes*. In: 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV). June 10-13, 2019, Eindhoven, the Netherlands.

[10]. Vlakveld, W. (2019). *Veiligheidseffecten van rijtaakondersteunende systemen*. Bijlage bij het convenant van de ADAS Alliantie. R-2019-14. SWOV, Den Haag.

[11]. Høye, A. (2016). *How would increasing seat belt use affect the number of killed or seriously injured light vehicle occupants?* In: Accident Analysis & Prevention, vol. 88, p. 175-186.

[12]. Elvik, R., Høye, A., Vaa, T. & Sørensen, M. (2009). *The handbook of road safety measures*. Second edition. Emerald, UK.

[13]. Elliott, M.R., Kallan, M.J., Durbin, D.R. & Winston, F.K. (2006). *Effectiveness of child safety seats vs seat belts in reducing risk for death in children in passenger vehicle crashes. In: Archives of Pediatrics & Adolescent Medicine, vol. 160, nr. 6, p. 617-621.*

[14]. Zaloshnja, E., Miller, T.R. & Hendrie, D. (2007). *Effectiveness of child safety seats vs safety belts for children aged 2 to 3 years*. In: Archives of Pediatrics & Adolescent Medicine, vol. 161, nr. 1, p. 65-68.

[15]. Asbridge, M., Ogilvie, R., Wilson, M. & Hayden, J. (2018). *The impact of booster seat use on child injury and mortality: Systematic review and meta-analysis of observational studies of booster seat effectiveness*. In: Accident Analysis & Prevention, vol. 119, p. 50-57.

[16]. EuroNCAP (2021). *Side Pole*. EuroNCAP. Accessed on 11-06-2021 at https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/adult-occupant-protection/lateral-impact/side-pole/.

[17]. Glassbrenner, D. & Starnes, M. (2009). *Lives saved calculations for seat belts and frontal air bags*. NHTSA Technical Report DOT HS 811 206.

[18]. Høye, A. (2010). *Are airbags a dangerous safety measure? A meta-analysis of the effects of frontal airbags on driver fatalities*. In: Accident Analysis & Prevention, vol. 42, nr. 6, p. 2030-2040.

[19]. D'Elia, A., Newstead, S. & Scully, J. (2013). *Evaluation of vehicle side airbag effectiveness in Victoria, Australia*. In: Accident Analysis & Prevention, vol. 54, p. 67-72.

[20]. Ferguson, S.A. (2007). *The effectiveness of electronic stability control in reducing real-world crashes: A literature review*. In: Traffic Injury Prevention, vol. 8, nr. 4, p. 329-338.

[21]. Fildes, B., Keall, M., Bos, N., Lie, A., et al. (2015). *Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes*. In: Accident Analysis & Prevention, vol. 81, p. 24-29.

[22]. Cicchino, J.B. (2017). *Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates*. In: Accident Analysis & Prevention, vol. 99, p. 142-152.

[23]. Douglas, J.W. & Schafer, T.C. (1971). *The Chrysler "Sure-Brake" – The first production four-wheel anti-skid system*. In: SAE Transactions, vol. 80, p. 999-1008.

[24]. Ministerie van VenW (1992). *Besluit van 14 februari 1992, houdende wijziging van het Reglement verkeersregels en verkeerstekens 1990*. Staatsblad van het Koninkrijk der Nederlanden, stb-1992-100. Ministerie van Verkeer en Waterstaat.

[25]. EC (1996). *Commission Directive 96/37/EC of 17 June 1996 adapting to technical progress Council Directive 74/408/EEC relating to the interior fittings of motor vehicles (strength of seats and of their anchorages)*. Document 31996L0037. European Commission, Brussels.

[26]. European Parliament (2009). *Regulation (EC) No 661/2009 of the European Parliament and of the Council of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor (Text with EEA relevance)*. Document 32009R0661. Official Journal of the European Union.

[27]. UNECE (2021). *UN Regulations (Addenda to the 1958 Agreement)*. United Nations Economic Commission for Europe (UNECE). Accessed on 20-12-2021 at https://unece.org/un-regulations-addenda-1958-agreement.

[28]. Cummings, P. & Grossman, D.C. (2007). *Antilock brakes and the risk of driver injury in a crash: A case–control study*. In: Accident Analysis & Prevention, vol. 39, nr. 5, p. 995-1000.

[29]. Burton, D., Delaney, A., Newstead, S., Logan, S., et al. (2004). *Evaluation of anti-lock braking systems effectiveness*. Report 04/01. Royal Automobile Club of Victoria Ltd, Australia.

[30]. EuroNCAP (2021). *Head impact*. EuroNCAP. Accessed on 14-06-2021 at https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/vulnerable-road-user-vru-protection/head-impact/.

[31]. European Parliament (2019). *Regulation (EU) No 540/2014 of the European Parliament and of the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems, and amending Directive 2007/46/EC and repealing Directive 70/157/EEC (Text with EEA relevance)*. Document 02014R0540-20190527.

[32]. Lewin, T. (2005). *Autoliv designs pop-up hood for Jaguar XK*. Automotive News Europe. Accessed on 15-06-2021 at https://europe.autonews.com/article/20050905/ANE/509050820/autoliv-designs-pop-up-hood-for-jaguar-xk.

[33]. Jakobsson, L., Broberg, T., Karlsson, H., Fredriksson, A., et al. (2013). *Pedestrian airbag technology – A production system*. In: 23rd International Technical Conference on the Enhanced Safety of Vehicles (ESV). May 27-30, 2013, Seoul, South Korea.

[34]. Konet, H., Sato, M., Schiller, T., Christensen, A., et al. (2011). *Development of Approaching Vehicle Sound for Pedestrians (VSP) for Quiet Electric Vehicles*. In: SAE International Journal of Engines, vol. 4, nr. 1, p. 1217-1224.

[35]. EC (2019). *Road safety: Commission welcomes agreement on new EU rules to help save lives*. Press release. European Commission, Brussels.

[36]. CBS (2020). *Motorvoertuigenpark; type, leeftijdsklasse, 1 januari. CBS*. Accessed on 11-06-2021 at https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82044NED/table?dl=4E048.

[37]. Fredette, M., Mambu, L.S., Chouinard, A. & Bellavance, F. (2008). Safety impacts due to the incompatibility of SUVs, minivans, and pickup trucks in two-vehicle collisions. In: Accident Analysis & Prevention, vol. 40, nr. 6, p. 1987-1995.

[38]. Monfort, S.S. & Nolan, J.M. (2019). Trends in aggressivity and driver risk for cars, SUVs, and pickups: Vehicle incompatibility from 1989 to 2016. In: Traffic Injury Prevention, vol. 20, nr. sup1, p. S92-S96.

[39]. Schipper, L. (2011). Automobile use, fuel economy and CO2 emissions in industrialized countries: Encouraging trends through 2008? In: Transport Policy, vol. 18, nr. 2, p. 358-372.

[40]. Hoogvelt, R.B.J., Vries, Y.W.R. de, Margarites, D., Tillaart, E. van den, et al. (2004). Impact of sport utility vehicles on traffic safety and the environment in The Netherlands. Report 04.OR.SA.065.1/RH. TNO Automotive, Delft, The Netherlands.

[41]. Baker, B.C., Nolan, J.M., O'Neill, B. & Genetos, A.P. (2008). Crash compatibility between cars and light trucks: Benefits of lowering front-end energy-absorbing structure in SUVs and pickups. In: Accident Analysis & Prevention, vol. 40, nr. 1, p. 116-125.

[42]. Ossiander, E.M., Koepsell, T.D. & McKnight, B. (2013). Will the light truck bumper height-matching standard reduce deaths in cars? In: Accident Analysis & Prevention, vol. 51, p. 292-300.

[43]. Ashmead, D.H., Grantham, D.W., Maloff, E.S., Hornsby, B., et al. (2012). Auditory perception of motor vehicle travel paths. In: Human Factors, vol. 54, nr. 3, p. 437-453.

[44]. Barton, B.K., Ulrich, T.A. & Lew, R. (2012). Auditory detection and localization of approaching vehicles. In: Accident Analysis & Prevention, vol. 49, p. 347-353.

[45]. Mori, Y. & Mizohata, M. (1995). Characteristics of older road users and their effect on road safety. In: Accident Analysis & Prevention, vol. 27, nr. 3, p. 391-404.

[46]. Stelling-Kończak, A., Hagenzieker, M. & Wee, G.P. van (2015). Traffic sounds and cycling safety: The use of electronic devices by cyclists and the quietness of hybrid and electric cars. In: Transport Reviews, vol. 35, nr. 4, p. 422-444.

[47]. European Parliament (2017). Commission Delegated Regulation (EU) 2017/1576 of 26 June 2017 amending Regulation (EU) No 540/2014 of the European Parliament and of the Council as regards the Acoustic Vehicle Alerting System requirements for vehicle EU-type approval (Text with EEA relevance). Document 32017R1576. Official Journal of the European Union, Brussels.

[48]. Fleury, S., Jamet, É., Roussarie, V., Bosc, L., et al. (2016). Effect of additional warning sounds on pedestrians' detection of electric vehicles: An ecological approach. In: Accident Analysis & Prevention, vol. 97, p. 176-185.

[49]. González-Hernández, J.M., Peral-Orts, R., Campillo-Davo, N., Poveda-Martínez, P., et al. (2017). Assessment of warning sound detectability for electric vehicles by outdoor tests. In: European Acoustics Association (EAA).

[50]. Tsuruta-Hamamura, M., Kobayashi, T., Kosuge, T., Tsujinaga, T., et al. (2019). Design of approach informing sound for quiet vehicles that indicates a car traveling. In: INTER-NOISE. June 16-19, 2019, Madrid, Spain.

[51]. Sun, P., Bisschop, R., Niu, H. & Huang, X. (2020). *A review of battery fires in electric vehicles*. In: Fire Technology, vol. 56, nr. 4, p. 1361-1410.

[52]. Berends, E.M. (2009). *De invloed van automassa op het letselrisico bij botsingen tussen twee personenauto's. Een kwantitatieve analyse [The influence of vehicle mass on the injury rate in collisions between two passenger cars. A quantitative analysis]*. R-2009-5 [Summary in English]. SWOV, Leidschendam.

[53]. Fouda Mbarga, N., Abubakari, A.-R., Aminde, L.N. & Morgan, A.R. (2018). *Seatbelt use and risk of major injuries sustained by vehicle occupants during motor-vehicle crashes: a systematic review and meta-analysis of cohort studies*. In: BMC Public Health, vol. 18, nr. 1, p. 1413.

[54]. Ekambaram, K., Frampton, R. & Lenard, J. (2019). *Factors associated with chest injuries to front seat occupants in frontal impacts*. In: Traffic Injury Prevention, vol. 20, nr. sup2, p. S37-S42.

[55]. Bose, D., Segui-Gomez, M. & Crandall, J.R. (2011). *Vulnerability of female drivers involved in motor vehicle crashes: an analysis of US population at risk*. In: American Journal of Public Health, vol. 101, nr. 12, p. 2368-2373.

[56]. Linder, A. & Svensson, M.Y. (2019). *Road safety: the average male as a norm in vehicle occupant crash safety assessment*. In: Interdisciplinary Science Reviews, vol. 44, nr. 2, p. 140-153.

[57]. Linder, A. & Svedberg, W. (2019). *Review of average sized male and female occupant models in European regulatory safety assessment tests and European laws: Gaps and bridging suggestions*. In: Accident Analysis & Prevention, vol. 127, p. 156-162.

[58]. Ridella, S., Rupp, J. & Poland, K. (2012). *Age-related differences in AIS 3+ crash injury risk, types, causation and mechanisms*. In: Proceedings of the Internatonal IRCOBI Conference on the Biomechanics of Injury. September 12-14, 2012, Dublin, Ireland.

[59]. Goudappel Coffeng (2010). *Beveiligingsmiddelen in de auto 2010*. Goudappel Coffeng in opdracht van Directoraat-Generaal Rijkswaterstaat, Dienst Verkeer en Scheepvaart DVS, Delft.

[60]. Mak, P. (2020). *Apparatuurgebruik, gordeldracht en gebruik kinderzitjes door automobilisten en chauffeurs: in auto's, bestelwagens en vrachtwagens*. Rijkswaterstaat. Onderzoek uitgevoerd door NDC Nederland, Goudappel Coffeng.

[61]. Davidse, R.J., Duijvenvoorde, K. van & Louwerse, W.J.R. (2020). *Dodelijke verkeersongevallen op rijkswegen in 2019. Analyse van ongevals- en letselfactoren en daaruit volgende aanknopingspunten voor maatregelen [Fatal road crashes on national roads in 2019. Analysis of crash and injury factors and resulting potential countermeasures]*. R-2020-29 [Summary in English]. SWOV, Den Haag.

[62]. Davidse, R.J., Duijvenvoorde, K. van & Louwerse, W.J.R. (2020). *Dodelijke verkeersongevallen op rijkswegen in 2018. Analyse van ongevals- en letselfactoren en daaruit volgende aanknopingspunten voor maatregelen [Fatal road crashes on national roads in 2018. Analysis of crash and injury factors and resulting potential countermeasures]*. R-2020-26 [Summary in English]. SWOV, Den Haag.

[63]. NSIA (2020). Report on a head-on collision between a passenger car and a van on the E39 at Austefjorden, Volda, Møre og Romsdal on 20 October 2019. Report 2020-07. Norwegian Safety Investigation Authority, Lillestrøm, Norway.

[64]. Acar, B.S., Edwards, A.M. & Aldah, M. (2018). Correct use of three-point seatbelt by pregnant occupants. In: Safety, vol. 4, nr. 1, p. 1.

[65]. McMurry, T.L., Forman, J.L., Shaw, G. & Crandall, J.R. (2020). Evaluating the influence of knee airbags on lower limb and whole-body injury. In: Traffic Inj Prev, vol. 21, nr. 1, p. 72-77.

[66]. Hallman, J.J., Brasel, K.J., Yoganandan, N. & Pintar, F.A. (2009). Splenic trauma as an adverse effect of torso-protecting side airbags: biomechanical and case evidence. In: Annals of advances in automotive medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference, vol. 53, nr. 13-24.

[67]. NHTSA (2008). Counts of frontal airbag related fatalities and seriously injured persons. AB0708. Department of Transportation DOT, National Highway Traffic Safety Administration NHTSA, National Center for Statistics & Analysis NCSA, Washington, D.C.

[68]. Funk, J.R., Cormier, J.M., Bain, C.E., Wirth, J.L., et al. (2012). Factors affecting ejection risk in rollover crashes. In: 56th AAAM Annual Conference Annals of Advances in Automotive Medicine. October 14-17, 2012. p. 203-2011.

[69]. Trempel, R.E., Zuby, D.S. & Edwards, M.A. (2016). IIHS head restraint ratings and insurance injury claim rates. In: Traffic Injury Prevention, vol. 17, nr. 6, p. 590-596.

[70]. Schoon, C.C. (1995). Technische aspecten omtrent aanwezigheid en gebruik van hoofdsteunen. Een studie uitgevoerd ten behoeve van de RAI [Technical aspects concerning the presence and use of head rests]. R-95-30 [Summary in English]. SWOV, Leidschendam.

[71]. Viano, D.C. & Gargan, M.F. (1996). Headrest position during normal driving: Implication to neck injury risk in rear crashes. In: Accident Analysis & Prevention, vol. 28, nr. 6, p. 665-674.

[72]. Strandroth, J., Rizzi, M., Olai, M., Lie, A., et al. (2012). The effects of studded tires on fatal crashes with passenger cars and the benefits of electronic stability control (ESC) in Swedish winter driving. In: Accident Analysis & Prevention, vol. 45, p. 50-60.

[73]. Malmivuo, M., Luoma, J. & Porthin, M. (2017). Studded and unstudded winter tires in fatal road accidents in Finland. In: Traffic Injury Prevention, vol. 18, nr. 5, p. 550-555.

[74]. TCS (2009). Leistungs- und kostenvergleich sommer-, winter- und ganzjahresreifen. Touring Club Schweiz, Emmen (Luzern), Zwitserland.

[75]. ANWB (2021). *Winterbanden en sneeuwkettingen in het buitenland*. Accessed on 01-10-2021 at https://www.anwb.nl/auto/banden/winterbanden/winterbanden-in-het-buitenland.

[76]. Garrott, W.R. & Mazzae, E.N. (1999). An overview of the National Highway Traffic Safety Administration's light vehicle Antilock Brake Systems research program. Technical Paper1999-01-1286. SAE International.

[77]. Ashenbrenner, K.M., Biehl, B. & Wurm, G.W. (1987). Einfluss Der Risikokompensation auf die Wirkung von Verkehrsicherheitsmassnahmen am Beispiel ABS. Schriftenreihe Unfall- und

Sicherheitsforschung Strassenverkehr. Heft 63, 65-70. Bundesanstalt für Strassenwesen (BASt), Bergisch Gladbach.

[78]. Mazzae, E., Garrott, W.R. & Barickman, F. (2001). *NHTSA light vehicle Antilock Brake System research program task 7.1: Examination of ABS-related driver behavioral adaptation – license plate study*. DOT HS 809 430.

[79]. Erke, A. (2008). *Effects of electronic stability control (ESC) on accidents: A review of empirical evidence*. In: Accident Analysis & Prevention, vol. 40, nr. 1, p. 167-173.

[80]. Christoph, M.W.T. (2010). *Schatting van verkeersveiligheidseffecten van intelligente voertuigsystemen. Een literatuurstudie [Estimate of the safety effects of intelligent vehicle systems. A literature study]*. R-2010-8 [Summary in English]. SWOV, Leidschendam.

[81]. Arbogast, K.B., Durbin, D.R., Cornejo, R.A., Kallan, M.J., et al. (2004). *An evaluation of the effectiveness of forward facing child restraint systems*. In: Accident Analysis & Prevention, vol. 36, nr. 4, p. 585-589.

[82]. Nance, M.L., Lutz, N., Arbogast, K.B., Cornejo, R.A., et al. (2004). *Optimal restraint reduces the risk of abdominal injury in children involved in motor vehicle crashes*. In: Annals of surgery, vol. 239, nr. 1, p. 127-131.

[83]. Cornelissen, M., Kemler, E. & Hermans, M. (2018). *Veilig vervoer van kinderen in de auto. Onderzoek bij kinderen van 0 t/m 8 jaar*. Rapport 758. VeiligheidNL, Amsterdam.

[84]. Schoeters, A. & Lequeux, Q. (2018). *Klikken we onze kinderen wel veilig vast? Resultaten van de nationale Vias-gedragsmeting over het gebruik van kinderbeveiligingssystemen 2017*. Vias institute –Kenniscentrum Verkeersveiligheid, Brussel.

[85]. Kapoor, T., Altenhof, W., Snowdon, A., Howard, A., et al. (2011). *A numerical investigation into the effect of CRS misuse on the injury potential of children in frontal and side impact crashes*. In: Accident Analysis & Prevention, vol. 43, nr. 4, p. 1438-1450.

[86]. Ma, X., Layde, P. & Zhu, S. (2012). *Association between child restraint systems use and injury in motor vehicle crashes*. In: Academic Emergency Medicine, vol. 19, nr. 8, p. 916-923.

[87]. Oh, C., Kang, Y.-s. & Kim, W. (2008). *Assessing the safety benefits of an advanced vehicular technology for protecting pedestrians*. In: Accident Analysis & Prevention, vol. 40, nr. 3, p. 935-942.

[88]. Fredriksson, R. & Rosén, E.A.O. (2014). *Head injury reduction potential of integrated pedestrian protection systems based on accident and experimental data – Benefit of combining passive and active systems*. In: IRCOBI conference 2014. Berlin, Germany. p. 603-613.

[89]. Rodarius, C., Mordaka, J. & Versmissen, T. (2008). *Bicycle safety in bicycle to car accidents*. TNO-033-HM-2008-00354. TNO.

[90]. EU (2020). *UN Regulation No 127 – Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance [2020/638]*. PUB/2020/334. Official Journal of the European Union, Brussels.

[91]. Hermitte, T. (2016). *Passenger car -Technical defect / Maintenance*. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Accessed on 05-11-2021 at www.roadsafety-dss.eu.

[92]. RDW (2021). *APK-keuringsschema*. Accessed on 16-06-2021 at https://www.rdw.nl/particulier/paginas/apk-keuringsschema.

[93]. Rijksoverheid (2020). *Van Nieuwenhuizen stelt oldtimers vrij van APK-plicht*. Ministerie van Infrastructuur en Waterstaat. Accessed on 16-06-2021 at https://www.rijksoverheid.nl/actueel/nieuws/2020/12/11/van-nieuwenhuizen-stelt-oldtimers-vrij-van-apk-plicht.

[94]. Lie, A. & Tingvall, C. (2002). *How do Euro NCAP results correlate with real-life injury risks? A paired comparison study of car-to-car crashes*. In: Traffic Injury Prevention, vol. 3, nr. 4, p. 288-293.

[95]. Kullgren, A., Lie, A. & Tingvall, C. (2010). *Comparison between Euro NCAP test results and real-world crash data*. In: Traffic Injury Prevention, vol. 11, nr. 6, p. 587-593.

[96]. Strandroth, J., Rizzi, M., Sternlund, S., Lie, A., et al. (2011). *The correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results*. In: Traffic Injury Prevention, vol. 12, nr. 6, p. 604-613.

[97]. Pastor, C. (2013). *Correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results*. In: 23rd Enhanced Safety of Vehicles Conference. May 27-30, 2013, Seoul, Korea.

[98]. ETSC (2016). *How safe are new cars sold in the EU? An analysis of the market penetration of Euro NCAP-rated cars*. PIN Flash report 30. European Transport Safety Council.

[99]. EC (2018). *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018/... and repealing Regulations (EC) No 78/2009, (EC) No 79/2009 and (EC) No 661/2009*. COM/2018/286 final - 2018/0145 (COD). European Commission, Brussels.

[100]. Minister van JenV (2018). *Aanpak rijden onder invloed van alcohol*. 29398-588. Brief regering dd. 7 maart 2018. F.B.J. Grapperhaus, minister van Justitie en Veiligheid en C. van Nieuwenhuizen Wijbenga, minister van Infrastructuur en Waterstaat.

[101]. ETSC (2021). *Intelligent Speed Assistance set for launch on all new EU vehicle types from 2022*. European Transport Safety Council. Accessed on 24-06-2021 at https://etsc.eu/intelligent-speed-assistance-set-for-launch-on-all-new-eu-vehicle-types-from-2022/.

[102]. Carter, P.M., Flannagan, C.A.C., Reed, M.P., Cunningham, R.M., et al. (2014). *Comparing the effects of age, BMI and gender on severe injury (AIS 3+) in motor-vehicle crashes*. In: Accident Analysis & Prevention, vol. 72, p. 146-160.

[103]. Maarseveen, R. van, Tijm, J. & Zwaneveld, P. (2018). *De fiscale behandeling van voertuigveiligheid*. CPB Policy Brief 2018/11. Centraal Planbureau, Den Haag.

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