Front passenger airbag interaction with restrained forward-facing children

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Abstract

This study investigates whether the front passenger airbag disabling strategy of turning the airbag off for all children when occupying the front seat (in countries where this is applicable), is valid for modern airbag designs. Passenger airbag technologies have evolved over the years, providing, for example, better balanced inflators and advanced foldings with improved positioning behaviour of the airbag.

Frontal impact tests with a variation of restraint child crash dummies, of varied seat positions, booster types, crash pulses and sitting postures demonstrated relative positive or comparable, effect for activated airbag compared to no airbag. In addition, some typical misuse cases (seatbelt under arm, seatbelt behind the back) were evaluated, where it was shown clearly more robust using the airbag to help protect the child.

Based on the results, Volvo Cars has revised its airbag disabling strategy for restrained forward facing children travelling in car models with front passenger airbag designs as tested in this study. For these specific car models it is revised to recommend that the airbag should be Enabled for all forward-facing restrained child occupants (as for adults), while kept Disabled for all rearward-facing children.

Introduction

Front passenger airbags have developed significantly since their introduction in the late 1980s. Most requirements and recommendations regarding passenger airbags and children are based on first-generation passenger airbags introduced in the late 1980s/early 1990s. Real world data at that time highlighted the incidences of child fatalities in relation to front passenger airbags (Winston et al. 1996, Braver et al. 1997, Arbogast et al. 1999). Based on this, different recommendations in different parts of the world came into effect. In some countries, children were prohibited in the front seat. In other countries, recommendations requested the passenger airbag to be switched off for children, with different limits on stature or age in different countries. In Sweden, the vehicle industry, together with other stakeholders, signed an agreement in 2006 urging front passenger airbag switch-off (manually by switch or at a workshop) to facilitate the use of the front passenger seat by children. The agreement in 2006 stated that airbag switch-off was required for children up to 140 cm. In 2016, the agreement was updated partly based on the research presented in this study (Folksam, 2017).

Passenger airbag technologies have evolved over the years, providing, for example, better balanced inflators and advanced foldings with improved positioning behaviour of the airbag. Overall, a modern airbag exhibits a much different behaviour than the first-generation airbags. Specifically, the FMVSS208 Frontal Occupant Protection update in 2002 (NHTSA, 2001) paved the way towards the important features of improving occupant and airbag interaction.

All front-seat passenger regulatory and consumer information testing includes deployment of front passenger airbags. Seatbelt and airbag technologies are working together as an integrated safety system. No standardised testing involves front-seat passenger evaluation using seatbelt only. Hence, the developments of seatbelt technology are not obviously controlled for the protection of occupants occupying the front passenger seat with the airbag disabled.

The objective of this study is to investigate whether the disabling strategy still apply for modern front passenger airbag designs. Specifically, the focus here is on restrained forward-facing children from the size of a 3YO. Smaller children are optimally protected in rearward-facing child seats. A front passenger airbag will likely not provide extra protection to the child in the rearward-facing seat and is believed to be hazardous, especially for those rearward-facing seats mounted in close proximity to the dashboard.

Methods

Several studies were performed to investigate whether the disabling strategy applies for modern front passenger airbag designs. Airbag deployments were studied in crash tests with vehicles containing different generations of airbag technologies, ranging from 1992 – 2016, with the purpose to categorise how the airbag interacted with an occupant during deployment. Computer crash simulations and physical crash tests were performed to further understand the interaction between a forward facing child occupant and the airbag in different frontal impact situations. This paper will specifically focus on the crash tests performed for one selected modern passenger airbag design.

Forty two frontal impact sled tests were performed in complete vehicle environment for a selected modern passenger airbag design. The vehicle chosen is representative of a Volvo car introduced from model year 2007 and later. For all of these models, the front passenger airbag design is representative of modern front passenger airbags, common on the market for approximately the last decade. The specific airbag and car model used in the study was identified as being among the more challenging designs, based on the airbag deployment study. The airbag is top-mounted, with a size of approximately 120 litres. The deployment pattern is shown in Fig. 1, and features positioning characteristics with little or no vertical movement relative to the occupant.

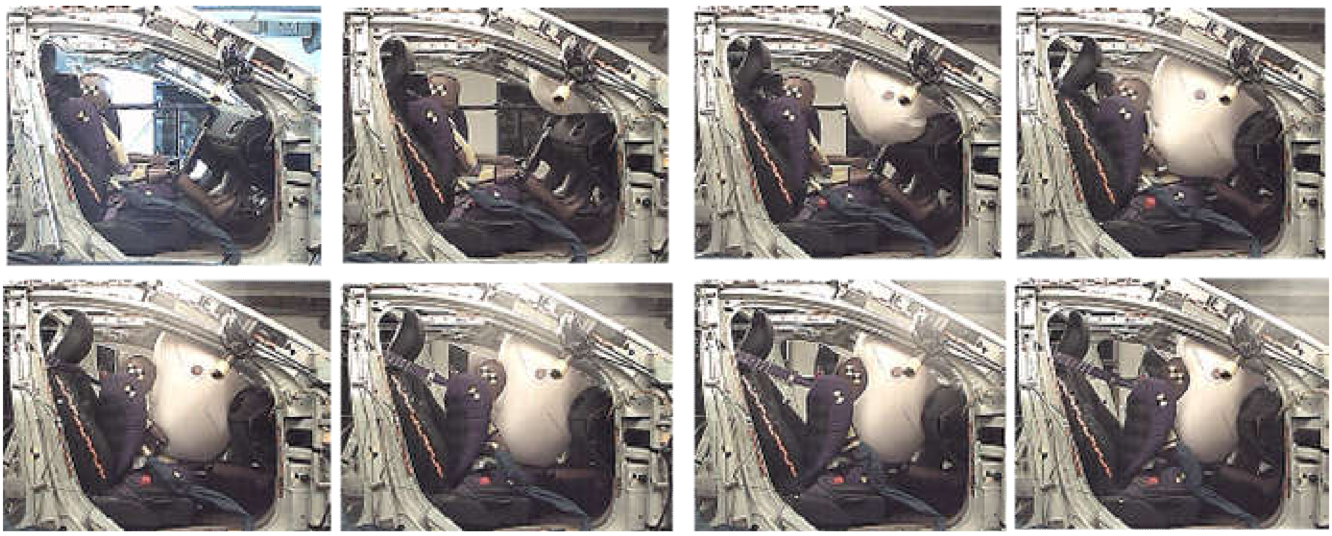

Fig. 1. Airbag deployment characteristics, from top left to bottom right.

In total, 19 different frontal impact situations were evaluated, comparing with and without airbag activation (see Appendix 1). Restrained child crash test dummies (3YO, 6YO, 10YO), of varied seat positions, booster types, crash pulses and sitting postures (up-right and forward leaning), were tested. In addition, some typical misuse cases (seatbelt under arm, seatbelt behind the back) were evaluated. The tests are described in detail in Heurlin et al. 2016, a summary is given in this paper.

The sled test rig comprises a complete interior of the car as shown in Fig. 2. The three different crash pulses (see Fig. 3) represent a selection of frontal impacts of varied overlap, impact speed and counterpart stiffness. Crash pulse A was used for most situations tested. It was selected to represent a worst-case scenario, maximising interaction between the airbag and the forward-facing child dummy. Pulse B is different with respect to acceleration vs time characteristics, while C represents a less severe crash pulse.

Fig. 2. Sled test set-up.

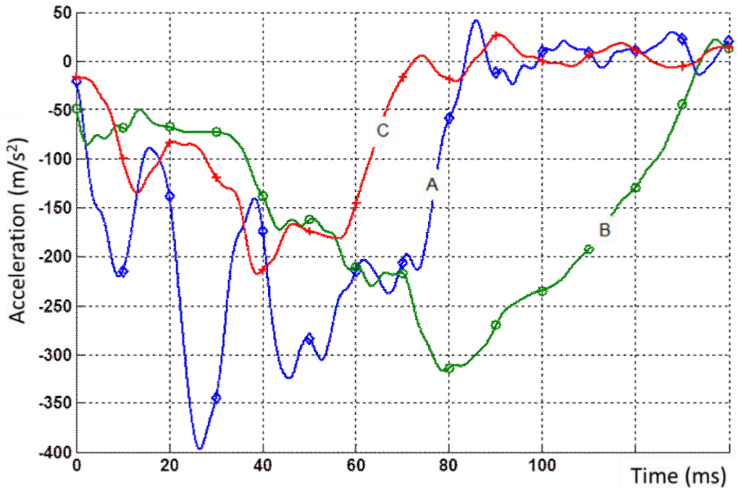

Fig. 3. The crash pulses used: blue = A; green = B; red = C.

In all tests, except some misuse/severe cases without airbag, the Q-series crash test dummies were used. In the misuse cases, the HIII 6YO dummy (HIII6y) was used, to avoid risking damage to the single available Q6 dummy. The seatbelt setting and airbag activation were according to standard triggering principles for the vehicle concerned and the crash pulse applied. Two different child restraints were tested: a booster cushion and a booster seat. The booster seat was a Volvo-branded booster seat, similar to the Britax Kid Plus. The booster cushion was the same type of seat, but with backrest removed. The 10YO crash test dummy was also tested restrained with seatbelt only. The three different seat positions were: longitudinal/height adjustments; mid/mid; full forward/mid; full rearward/low. Two different sitting postures were tested: upright, according to standard crash test position; and a forward leaning posture. The forward leaning posture simulated a potential pre-braking before the crash. The child dummy was leaned forward 200 mm to simulate the most forward position of a child after an emergency braking of approximately 1 g (Stockman et al. 2013). In addition, two typical seatbelt misuse cases were tested: shoulder-belt positioned under the arm and behind the back, respectively.

For each test situation, the dummy kinematics and responses were compared with and without the airbag activation. Some of the situations were chosen as they are frequently occurring situations, hence proving information on the potential benefit of the airbag in such scenarios. Other situations, such as the misuse and/or forward leaning posture, were chosen to evaluate the potential harm of the airbag in such a situation. Important aspects of kinematics evaluation include dummy airbag interaction, and whether the dummy is interacting with the "moving surface" of the deploying airbag. Published preliminary Injury Assessment Reference Values (IARV) for the Q-dummies were used to normalise the responses, enabling comparison of potential tolerance limits as well (UNECE 2015, Visvikis et al. 2014, Lemmen et al. 2003). For the situations where the HIII dummy was used (mainly in tests with seatbelt misuse and no airbag), detailed comparison of dummy responses was not carried out because of the mismatch in dummy models used. Instead, the dummy responses from the Q6 dummy tests were reviewed and comparison to the HIII 6YO tests was mainly via kinematics evaluation.

Results

To different extents, all 19 situations tested demonstrated relative positive or comparable, effect for activated airbag compared to no airbag. The influence of the airbag was relatively more pronounced in the more forward seat adjustment positions. In the misuse situations, it was clearly more robust using the airbag to help protect the child. Details on the results are published in Heurlin et al. 2016, some examples are presented in this paper.

Irrespective of child dummy size, the airbag is well deployed at time of head contact as shown in Fig. 4; comparing the kinematics of the Q3, Q6 and Q10 in mid-mid seat position. During the deployment of the airbag, there is no contact between airbag and child dummies, as illustrated in Fig. 1. The airbag is shown to provide a good support to the head and neck, as shown by the relatively lower head and neck responses for all the three child dummy sizes (Heurlin et al. 2016).

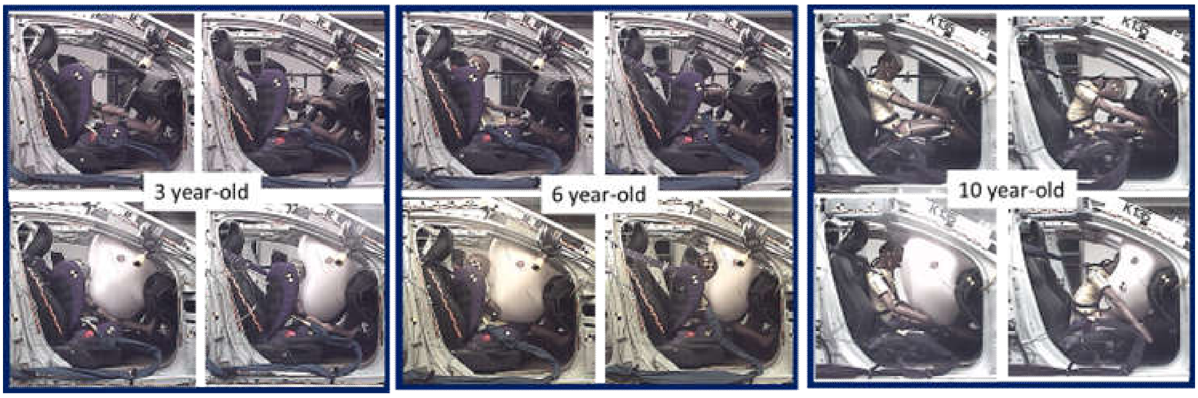

Fig. 4. Situations 2, 6 and 19, comparing the dummy sizes (Q3, Q6, Q10) in mid-mid seat position, crash pulse A. *Top row:* tests without airbag; *bottom row*: with airbags. First airbag contact (*left in each pair*), and maximum excursion (*right in each pair*).

The relative positive trend of airbag use is seen irrespective of seat position (Fig. 4-6). The influence of the airbag was relatively more pronounced in the more forward seat adjustment positions. Test situation 5 (Fig. 5) is simulating a 6YO in a booster seat, with the front passenger seat in the most forward and upward position. Although an unusual seating position, the results indicate that the airbag likely will add protection in this situation. As can be seen in Fig. 5, the Q6 sustains a head impact into the dashboard with the deactivated airbag, resulting in high head accelerations, which are significantly reduced in the test with airbag activation (Heurlin et al. 2016).

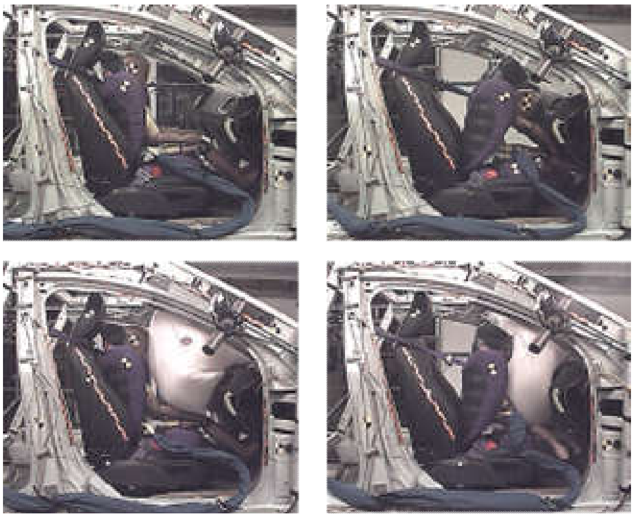

Fig. 5. Situation 5, Q6 in forward-mid position; *top row:* tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. excursion (*right*).

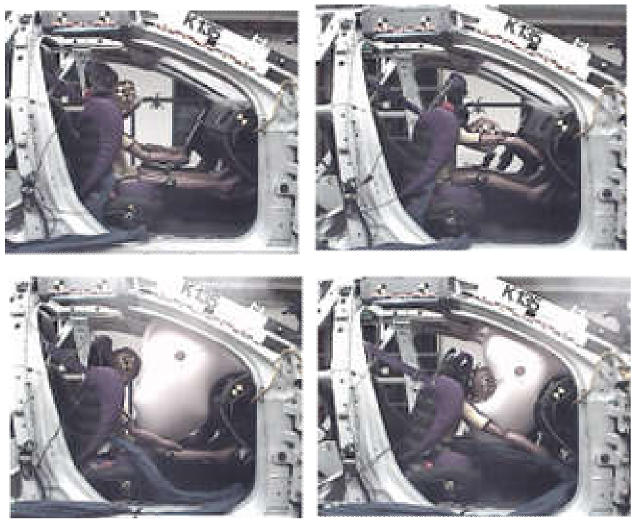

Fig. 6. Situation 10, Q6 in rearward-low position; *top row*: tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. excursion (*right*).

Most of the tests were run with booster seats. For comparison, tests with booster cushions were run for Q6 in mid-mid seat position in crash pulse A. Comparing the kinematics and dummy responses for the Q6 on booster cushions with the same set-up but with booster seats the same trends can be seen with respect to airbag versus no airbag (Heurlin et al. 2016). The relative positive effect of airbag is most pronounced for the situation with booster seat. This is mostly related to the relatively higher head and neck responses for the booster-seated child, likely due to differences in initial sitting posture and position. The Q6 on booster cushion in mid-mid seat position is rather similar in its responses to the test situation with Q6 in booster seat seated in most rearward seat position. This makes sense since a child in a booster seat will be positioned further forward, as compared to on a booster cushion, due to the backrest of the booster. In addition, tests were run without child restraint for the Q10 dummy in mid-mid position. The influence of the airbag follows the same trend as seen for the Q10 using booster cushion. Especially for the neck loads, a relative difference is seen, with the airbag helping to reduce the values below the IARV (Heurlin et al. 2016).

The same trend is seen irrespective of crash pulse, comparing pairwise with respect to airbag influence. When comparing crash pulses A and C, with Q3 and Q6 in mid-mid seat position, it can be seen that the dummy kinematics is influenced; resulting in a less forward excursion in pulse C (being a relatively low severity pulse), as compared to comparable test in pulse A (Heurlin et al. 2016). The pairwise comparison of dummy readings follows the same trend, although with lower overall values for crash pulse C, due to lower severity crash pulse. The same trend for airbag versus no airbag is seen when comparing crash pulses B with A for the Q6 using booster cushion, in mid-mid seat position.

Forward leaning / pre-brake situation

Three test situations were run with a Q6 in a forward leaning mode to simulate a pre-brake situation. Situations 12 and 13 are in mid-mid seat position. Two different pulses (A and B) were used to check the influence of the pulse shape with respect to timing and airbag interaction. The kinematics for test situation 12 is shown in Fig. 7.

To evaluate if a more forward initial seat position would differ from a mid-mid seat position, tests were run with a forward leaning Q6 crash dummy on a booster seat in the most forward seat position (situation 11). Crash pulse B was selected for this test situation. The kinematics for these tests are shown in Fig. 8. The occupant responses are well below the limit of IARV, and the airbag adds protection especially to the neck and head. Although being an unlikely seating position, this was mainly run to ensure a good airbag positioning, which was confirmed (see Fig. 8).

Fig. 7. Situation 12, Q6 forward leaning, mid-mid seat position, pulse B; *top row*: tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. forward position (*right*).

Fig. 8. Situation 11, Q6 forward leaning, forward seat position, pulse B; *top row*: tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. forward position (*right*).

Seatbelt misuse

Two different types of seatbelt misuse were tested to evaluate the effect of an airbag interaction with a child that was not restrained appropriately; under the arm and behind the back. In test situation 15 (Fig. 9), the belt was placed under the arm. Three test situations with the seatbelt placed behind the back were performed using the HIII6y/Q6, varying seat positions and crash pulses. Dummy kinematics for mid-mid seat position and crash pulse A is shown in Fig. 10. Results from all the seatbelt misuse test situations are presented in Heurlin et al. (2016). In all cases of airbag activation, the responses were well below the IARV values. For the non-airbag cases, the responses were multiple times higher, especially for the head, due to severe head impact into the dashboard. As the HIII 6YO was used in the non-airbag tests, no detailed dummy response comparisons are made.

Fig. 9. Situation 15, HIII6y /Q6, belt placed under the arm **mid-mid**, seat position, pulse A; *top row*: tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. forward position (*right*).

Fig. 10. Situations 16, HIII6y/Q6, belt placed behind the back **mid-mid** seat position, pulse A; *top row*: tests without airbag; *bottom row*: with airbag. First airbag contact (*left*), max. forward position (*right*).

Discussions

The situations in the test series were chosen to provide information facilitating a comparison on whether a restrained forward-facing child occupant sitting in the front passenger seat would benefit from an activated airbag in a frontal impact. The airbag improvements (especially with respect to inflator and folding techniques), and due to the fact that the seatbelt developments are driven together with airbags (whereby no stand-alone seatbelt evaluation is forced to be made) motivate this study. The results are primarily targeting countries in which the front seat may be used by child passengers and where it is required to actively switch on/off the front passenger airbag depending on who is occupying the seat. In the test series, the seat positions and child occupant sizes were combined to cover the most common positions, as well as including some extreme positions. Different child restraints, as well as a variety of crash pulses, were used in order to ascertain whether any major differences applied. In addition, some misuse cases were included to ensure that the child occupant injury risk would not be increased by activation of the airbag. Unrestrained was not considered, since the purpose of the study was to provide improved quality in disabling/enabling guidelines and not to evaluate the whole context of children in the front seat and interaction to airbags.

The contribution of the airbag was relatively more pronounced in the more forward seat adjustment positions, and less distinct in the more rearward seat adjustment positions. This is natural, as in the forward seat positions there is a higher likelihood of occupant interaction with the dashboard in situations with no airbag activation. In addition, the airbag interaction is less noticeable when the seat is moved backwards. The airbag helped not only to avoid head impacts but also provided a support in controlling the kinematics of the torso and neck, as well as the hands and arms. In the misuse situations (seatbelt under the arm and seatbelt behind the back), it was clearly more robust using the front passenger airbag to help protect the forward-facing child.

Booster seat was chosen for all the 3YO tested and most of the 6YO tested; while booster cushion as well as no booster was chosen for the 10YO. No major differences are seen between the different restraint types. In some countries, forward-facing child seats with internal harness are used for the youngest/smallest within the range of tests in this series. This type of seat was not included in this test series and might need further testing if judged not represented by the variation of tests (in-position tests as well as misuse situations) performed in this study.

In EU countries it is regulated by law that the front passenger airbag must be disabled when a rearward-facing child occupies the front seat. Johannsen et al. (2009) proposed that it might be feasible to design a front passenger airbag to be compatible with rearward-facing infant seats. However, the rearward-facing seats come in different sizes, including toddlers as well. These larger rearward-facing toddler seats are very different from the infant seats and are placed higher and in closer proximity to the instrument panel. They will most likely not benefit from an airbag activation, and could even be harmed by it.

Based on the crash tests presented in this study, in addition to the CAE crash simulations and the study or airbag deployment, Volvo Cars has revised its recommendations for restrained forward-facing children travelling in car models with front passenger airbag designs as tested in this study, see the list of car models in Appendix 2. For these specific car models it is recommended that the airbag should be Enabled for all forward-facing restrained child occupants (as for adults), while kept Disabled for all rearward-facing children. This type of airbag design (Fig. 1) is a common design in modern vehicles and it is encouraged that other car models are exerted for the same type of evaluation to establish if this will be applicable for a wider range of vehicles, in countries where children are allowed to sit in the front seat. An airbag disabling strategy that distinguishes between rearward-facing and forward-facing occupants is easier to communicate and to remember than age- or height-specific recommendations. By being clearer in its limits, such a strategy will most likely help to reduce the misuse cases and provide enhanced protection not only for the child occupants benefiting from the modern airbag design but also for adult occupants, who might otherwise have been without airbag protection. It is encouraged that similar studies are performed by other car manufacturers to evaluate whether this can be a more widely spread recommendation.

Conclusions

This study shows that a modern front passenger airbag, as tested in this study, can enhance protection to restrained forward-facing children (3YO–10YO). To different extents, all the situations tested demonstrated relative positive or comparable effect for activated airbag compared to no airbag. The contribution of the airbag was relatively more pronounced in the more forward seat adjustment positions, and less distinct in the more rearward seat adjustment positions. Improved head/neck kinematics, more margin for contact with hard surfaces, along with better control of hands/arms are among the benefits of the airbag, thus providing added protection to the forward-facing child. In the misuse situations (seatbelt under arm and seatbelt behind the back), it was clearly more robust using the front passenger airbag to help protect the forward-facing child.

Based on the results of this study, Volvo Cars has revised its recommendations for restrained forward-facing children travelling in car models with front passenger airbag designs as tested in this study. For these specific car models it is recommended that the airbag should be Enabled for all forward-facing restrained child occupants (as for adults), while kept Disabled for all rearward-facing children.

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APPENDIX 1

TEST SITUATIONS INCLUDED IN THIS STUDY;
EACH SITUATION WAS TESTED WITH AND WITHOUT AIRBAG ACTIVATION

Situation	**Crash pulse**	**Child dummy** (AB off/on)	**Child restraint**	**Seat position** (longitudinal+ height)	**Sitting posture /misuse**
1	A	Q3/Q3	booster seat	front + mid	upright
2	A	Q3/Q3	booster seat	mid + mid	upright
3	C	Q3/Q3	booster seat	mid + mid	upright
4	A	Q3/Q3	booster seat	rear + low	upright
5	A	Q6/Q6	booster seat	front + mid	upright
6	A	Q6/Q6	booster seat	mid + mid	upright
7	C	Q6/Q6	booster seat	mid + mid	upright
8	A	Q6/Q6	booster cushion	mid + mid	upright
9	B	HIII6y/Q6	booster cushion	mid + mid	upright
10	A	Q6/Q6	booster seat	rear + low	upright
11	B	Q6/Q6	booster seat	front + mid	forward leaning
12	B	Q6/Q6	booster seat	mid + mid	forward leaning
13	A	Q6/Q6	booster seat	mid + mid	forward leaning
14	A	HIII6y/Q6	booster seat	front + mid	belt behind back
15	A	HIII6y/Q6	booster seat	mid + mid	belt under arm
16	A	HIII6y/Q6	booster seat	mid + mid	belt behind back
17	B	HIII6y/Q6	booster seat	mid + mid	belt behind back
18	A	Q10/Q10	none	mid + mid	upright
19	A	Q10/Q10	booster cushion	mid + mid	upright

APPENDIX 2:

Volvo Cars' Child safety recommendation in the front seat, launched 2016

Available at: https://www.volvocars.com/intl/about/child-safety/child-safety-by-volvo

New child safety recommendation for children travelling in the front passenger seat of Volvo cars.

Volvo Cars' recommendation for the use of the front passenger airbag for children has been updated, thanks to advances in airbag technology in recent years.

Volvo Cars strongly recommends that children travel rearward facing as long as possible (up to 3-4 years old at the very minimum), and that all children up to 140 cm in height always use a child restraint when sitting in the front or the rear seat of the car.

Forward facing children travelling in the front passenger seat of a Volvo car[1] should have the passenger airbag turned on[2]. Children in rearward facing seats **must** have the passenger airbag turned off.

New recommendation, passenger airbag

If equipped, the passenger airbag cut-off switch is located on end of dashboard on the passenger side. It may vary visually depending upon model.

The ON/OFF position is clearly communicated in the Overhead Console (indication may vary in depending upon car model).

In newer vehicles, the airbag status is also presented in the Driver Information Module every time the status of the switch is changed.

[1] New recommendation valid and verified for the following models:

V40 (MY 2013-)	V40 Cross Country (MY 2013-)	S60/V60 (MY 2011-)	S60/V60 Cross Country (MY 2015-)	XC60 (MY 2009-)	V70 (MY 2008-)	XC70 (MY 2008-)	S80 (MY 2007-)	XC90 (MY 2016-)	S90/V90 (MY 2017-)	All future models
☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

Recommendation for older Volvo models

[2] Always check the legal regulations and child safety recommendations in your home country.
In some countries it is forbidden (or not recommended) for children to travel in the front passenger seat. In the EU a passenger airbag cut-off switch is standard. In the United States and Canada, children are strongly recommended to use the rear seat, and a manual passenger airbag cut-off switch is not available. In the rest of the World, a passenger airbag cut-off switch is a market option.