Novelty seating positions in automated vehicles: opportunities and challenges for child seats

Ines Levallois, Patryk Rećko, Faurecia Automotive Seating, France, Poland.
Katarina Bohman, Volvo Cars, Sweden.
François Renaudin, Dorel, France.

I.ABSTRACT

The European Project VIRTUAL explored possible configurations of novelty seating configurations in highly automated vehicles. Different vehicle seat arrangements were assessed in a prototype vehicle environment at 1:1 scale. Main interesting vehicle seating configurations for adults seated in highly automated vehicles are presented and possible opportunities and challenges for the child safety of such novelty seating configuration are discussed.

II.INTRODUCTION

With automated driving, the driver is no longer needed to be engaged in driving and thereby also becomes a passenger. This opens up the possibility for a more flexible vehicle interior when steering wheels and pedals are removed, and there is no longer a need for the driver to face the road ahead. The demands from users for more flexible vehicle interiors may thus increase. Several studies have investigated in user expectations of seating configurations in automated driving vehicles, indicating the desire of face-to-face seating configuration when travelling several in the vehicle and especially for longer trips [1][2][3]. However, besides user expectation, considerations must be given to the roominess of highly automated vehicles, the postural comfort of an occupant, the usage of the vehicle, the dynamic behavior of the car and its effect to the human body including also motion sickness.

As defined in SAE 3016 [4] Level 4 automated driving does not request the driver anymore to supervise the road, nor to act as a fallback driver. Various seat positions become therefore available. The aim was to find out main seating configuration and occupant postures which could be encountered in automated vehicles of Level 4. This study will review possible future seat arrangements in the available vehicle space which offer postural comfort, and which shall be further evaluated for adult and child safety.

III. METHOD

A workshop was conducted to explore novel seating configurations. Four persons participated in the workshop including research engineers from a car seat supplier, car manufacturer and child seat manufacturer, and one ergonomist from a car manufacturer.

A vehicle mock-up was used, representing the vehicle interior of a mid-size SUV *(Figure 1)*. The heating and ventilation system, the tunnel and wheelhouses have been removed. Up to 4 vehicle seats were installed in a vehicle buck in different seating configurations. The different seating configurations were recorded with photos and measurements of seat positions were taken. The participants tried the different configurations and discussed their advantages and disadvantages.

Several child seats were also installed in the various positions, and the challenges of these configurations were discussed.

Following child seats were used during the workshop:

- A R129 integral i-size convertible seat with Top Tether Maxi Cosi Axissfix ® (*Figure 2-A)*
- A R129 i-size base compatible Maxi Cosi 2Way base ® with an integral convertible shell Maxi Cosi 2Way Pearl ® and an infant seat Maxi Cosi Pebble+ ® (*Figure 2-B)*
- A R44 booster seat equipped with isofix connectors, Maxi Cosi Rodifx ® (*Figure 2-C)*

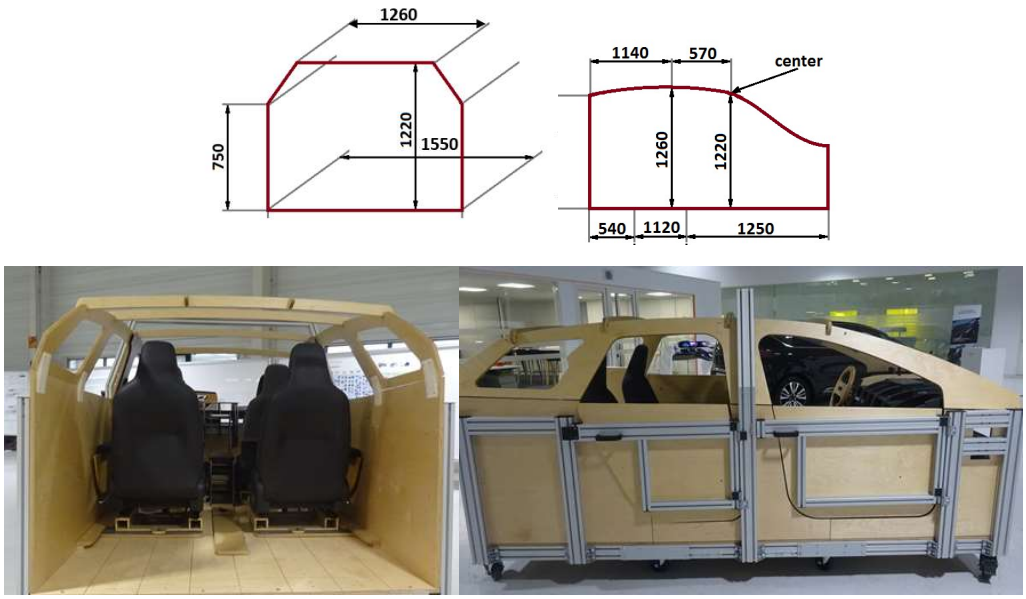

Figure 1 Top figure shows the interior volume of the vehicle space. The bottom figures show the mock-up.

Figure 2 CRS used during the workshop.

Terminology

In this study, three words are used to describe the vehicle interior seating configuration, how the seat is positioned and how the occupant is positioned in the seat:

- Seating configuration - describing the seat position in relation to each other, if they are forward facing, or rotated (swivel seat positions). Seating configurations can be described as “living room”, “face to face”, “campfire” etc.
- Seat position - includes internal adjustments of the seat itself, such as seat back angles, seat cushion angle, seat cushion height, and seat position in the vehicle longitudinal (x-) direction.
- Sitting posture – occupant posture in terms of upright/slouched/collapsed position of whole body, including arm and leg positions.

IV. RESULTS AND DISCUSSION

The first part of the study shall answer the question, which rotation angles could be obtained within the given space by the seats and which face-to-face positions are realistic for car occupants.

<u>Seat configurations including seats rotated around a vertical axis</u>

A. Both front seats were rotated inboards until interference of the seat slides. An outboard space was maintained to guarantee access to the seat belts on the B-pillar. Theoretically the seats could be rotated inboards each by a mean angle of 17°, but this resulted in knee and leg contacts between the occupants and it was considered as not comfortable by the occupants.

Figure 3 Rear view and top view of the seat configuration with 17° inboard rotated front seats.

B. In a second step, the rotation angle was reduced until no leg interference of the 2 occupants occurred and both occupants agreed that they do not feel disturbed by the person sitting in the adjacent seat. In this position a mean rotation angle of 11° was determined for each seat.

Figure 4 Top view of the seat configuration with 11° inboard rotated front seats.

C. One of the seats has been swiveled to a rear-facing position and the maximum available rotation angle of 20° has been obtained for each seat (*Figure 5*).
It shall be also noted that it was not possible due to limited space, to rotate a seat to a rearward-facing position with the occupant remaining on the seat and the presence of a 2nd seat in the same row.

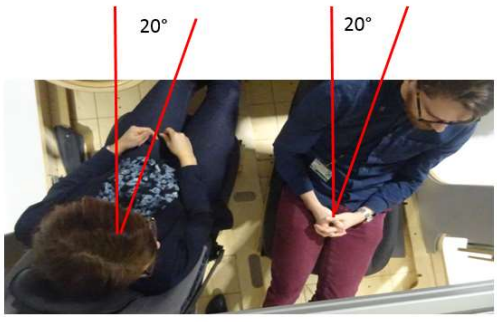

Figure 5 Top view of the seat configuration with passenger seat rotated rearwards, both seats with a rotational angle of 20°

D. The seats have been adjusted facing the forward direction laterally, (*Figure 6*). The volume in the vehicle does not allow to place the seats face-to-face, but only side-by-side. Arranging seats laterally was very space consuming and it limited the number of possible seating positions in the vehicle.

Figure 6 Two vehicle seats facing the direction of travel sideways.

E. Face to face rearward/forward-facing positions:
The seats were placed face-to-face and the amount of room needed for the legs was evaluated (*Figure 7*).

Figure 7 Face-to-face seat configuration

The needed distance between seats placed face-to-face is principally depending on the size of the shoes in the case an occupant cannot place its legs partially under the seat.
An initial distance of 480mm was considered as not comfortable and the occupants were requested to readjust the distance between the seats. The occupants started to consider a minimum distance of 580mm as acceptable. This space will depend on the height of the seat.

F. Face to face with parallel rotation
The occupants when placed face-to-face, rotated the seats approximately 12° (*Figure 8*) in order to be able to find space between the seats to stretch their legs.

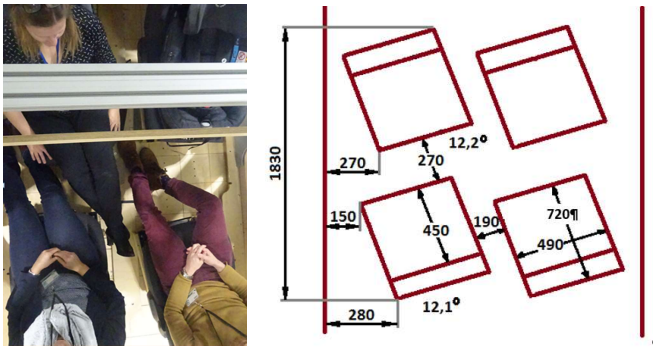

Figure 8 Top view of face to face configuration with all four seats rotated 12°.

The participants were very satisfied by this configuration as they did not feel discomfort due to limited feet/leg interaction with other occupants. In addition, this seating configuration is very compact, and the overall length does not exceed 1830 mm. A rotation of 12° was necessary of each seat to reach the shown position (*Figure 8*).

G. Face to face, all seats rotated inboards
A version of face to face configuration was made, by rotating all four seats 16° inboards into a star formation. This configuration is also called 'campfire' configuration (*Figure 9*). Occupants preferred this configuration over configuration E, due to less intense eye-to-eye contact with the adjacent occupant. However, occupants preferred configuration F over configuration G, due to limited space preventing them to stretch their legs in configuration G. The mean inward rotation angle of the seats was 16° in configuration G.

Figure 9 Face to face configuration, with all four seats rotated inboards 16°.

<u>Summary and conclusion for seat configurations with swiveled or rotated seating configurations.</u>
Prior to the physical try-out in the vehicle buck, several test participants thought that seat rotations would be a non-essential adjustment feature for automated driving vehicles when face-to-face seat arrangements were installed. However, by order of preference the participants preferred arrangement F over G and G over configuration E.
When rotating two front seats inboards towards each other (configurations A and B), a maximum rotation of 20° could be obtained. However, the most preferred position resulted in angles between 11° and 16°.
Even if this study has been conducted with a low number of participants and should be refined with a larger number of test persons, the following conclusion was drawn:

- In face-to-face seating configuration, additional rotational adjustment around its vertical axis is an essential adjustment feature to improve comfort in terms of leg/feet space as well as the social contact.
- It is recommended to study crash situations with forward and rearward facing occupants including inboard and outboard rotations of seats up to 20°.

Safety of children in different rotated or swiveled seating configurations

There are no compatibility problems between today's child seat volumes and future rotated or swiveled vehicle seating configurations. Rotation angles up to 20° inboard and outboard are possible and need to be studied (*Figure 10*).

Figure 10 Installation of a child seat in a campfire position with 16° inboard rotation.

Safety regulations (ECE 145 or FMVSS 225) for vehicle seats limit the isofix installation to a yaw angle of 10° and child seat regulation consider that all child seats are placed forward or rearward-facing. The seating configuration, with a child seat mounted on a 180° rotated front passenger seat was perceived as a comfortable seating configuration with good access and contact with the child seated opposite the adult. The adult could also have good contact with the child sitting beside. This family configuration felt like a relevant seating configuration where the driver still can be engaged as a driver.

Figure 11 A rearward facing child seat installed on the left side on the second row, and a forward-facing child seat installed in a front passenger seat swiveled 180° rearward.

Rotated front passenger seats introduce a new misuse case for child restraint systems: the installation of a rearward-facing child seat on a rearward-facing vehicle seat (*Figure 12*). This incorrect installation highlights the need of child restraint systems designed for the new seat configuration.

Figure 12 Incorrect installation of rearward-facing child seat in front passenger seat rotated 180° rearward facing.

Relaxed seat positions

The second part of the study reviewed reclined seat positions, used to increase comfort in situations when the occupant will not anymore have the task to supervise the road, to steer or to reach the pedals.

A. Reclined seat back

Occupants were requested to install in the forward-facing front seats and to recline to a position considered as comfortable (*Figure 13*).

Figure 13 Reclined seat back to relaxed position

There was no agreement among participants up to which seat back angle a comfortable posture could be reached and the group considered that the number of participants during the workshop was not large enough to take final conclusions.
The workshop was therefore complemented by a literature review on comfortable postures.

Literature review on preferred reclining angles

Comfortable postures can be explained with the method of 'comfort angles' or also called 'angles of least discomfort'. Jean-Marc Judic et al. [5] proposed a method to package seats in vehicles based on the method of least discomfort angles and which is more adapted to automated vehicles than the actual SAE recommended practices [6].

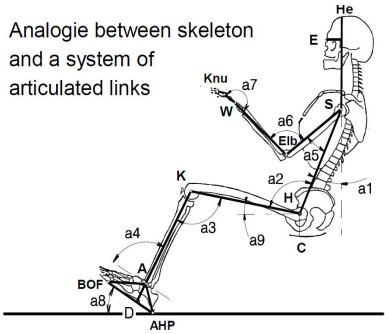

Figure 14 Comfort angles considered in comfort posture studies [5]

Comfort angles represent the preferred range of angles used by vehicle occupants regardless of the size of the occupant. To feel comfortable, occupants are seeking a posture in which they relieve the muscles assuring the maintenance and stabilization of the body to forces they undergo and in which they have to use a minimal muscular contraction to react to driving forces and to different tasks [5]. Numerous studies exist for the range of preferred comfort angles for drivers [7]. Few studies exist for passenger or rear seat occupant positions.

Kilincsoy et al. [8] conducted a postural comfort study for adjustable rear seats of a luxury sedan car in a laboratory environment. Different postures were studied: an upright, standard and relaxed

position. Based on 20 participants the trunk-thigh angle (a2 of figure 14) in the relaxed position was measured with a mean value of 118.9° and with a standard deviation of 10.5°.

Further comfort studies [7] reported preferred trunk-thigh angles up to a value of 130°.

Future relax seats may not only allow an increased trunk-thigh angle, but also be inclined more rearward by rotating the seat cushion and the seat back further rearward. For the time being an additional rearward inclination angle of maximum 20° is considered by the authors.

Today's luxury vehicle seats may have an upper seat back adjustment allowing the head and upper body (at shoulder level) to lean more forward. In Matthew Reed et al. [9] the effect of reclining a seat back on occupant posture was studied. It has been observed that passengers advance their head and upper body, when reclining the seat back to be able to see in a forward direction, possibly to see the horizon. It is expected that an upper body adjustment will be necessary for very reclined seats.

Summary and conclusion for novelty seats for relax positions:

To allow the prior mentioned evolutions in the sitting posture, relax seats may have adjustable upper seat backs and may offer adjustment angles in the range of 100 to 130° between the torso and the thighs. The possibility to adjust cushion angles of 15° to 35° shall be considered. It is also expected that shoulder adjuster with an adjustment range of about 15° are present.

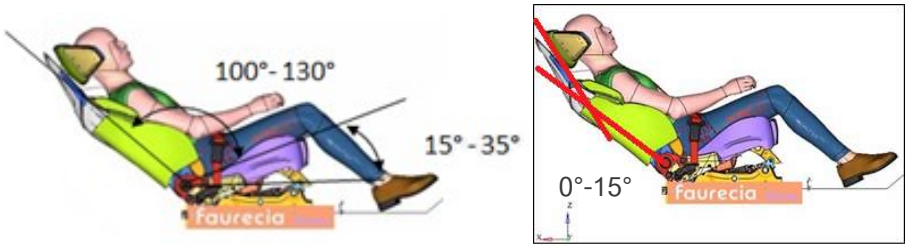

Figure 15 Relax seat adjustment possibilities

Safety of children in Relax seating configurations

The tested child seats are not compatible with relax seats in a reclined seating position. The booster seat tested in the workshop could not follow the reclined angle of the vehicle seat back, instead there was a gap between the booster back and vehicle seat back (*Figure 16*).

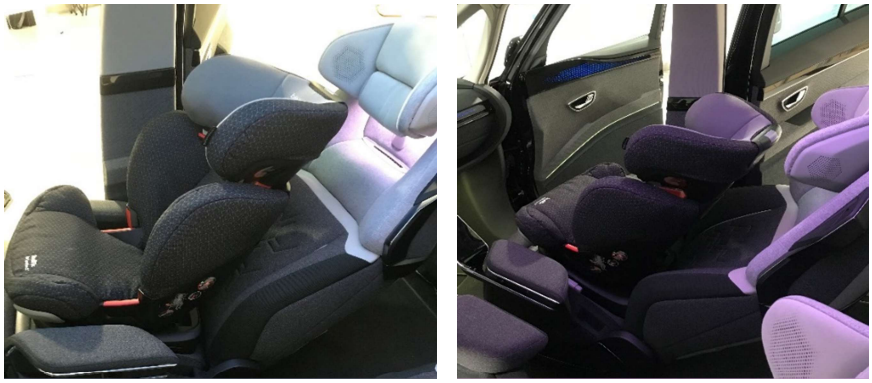

Figure 16 Booster seat incompatibility when seated in a reclined front passenger seat.

Studies of adults in reclined passenger seat, have shown challenges in terms of submarining but also increased lumbar spine injuries [10]. Before allowing children to travel in reclined seat position, it is important to evaluate the occupant safety for them as well.

There may be also limited space in the rear seat behind front passenger seat with reclined seat back (*Figure 17*), reducing the available space for forward excursion of the rear seat occupant during a frontal impact.

Figure 17 Example of reclined front passenger seat, reducing the space for the rear seat with a booster seat.

A solution to such situations could be a functionality which limits the reclining angle, in case of presence of rear seat occupants.

The face-to-face seating configuration offers great opportunity for families to travel in an environment with improved possibility for interaction between occupants. There are also safety opportunities for older children than infants and toddlers to travel rearward facing, a travel mode which is acknowledged as very safe (McMurry et al. 2018) [11].
However, this study highlights there are several occupant protection challenges in these new seating configurations. In face-to-face configurations, it may become confusing for the parent to keep apart what vehicle seat position fits with what type of CRS system, depending on if the CRS is forward facing or rearward facing the vehicle's direction of motion. Figure 12 shows an example of a rearward facing CRS installed incorrectly in a rotated front passenger seat. There is a need of designing CRS that can be installed in various seat positions and great care has to be taken to ensure that the installation instructions are easy to follow.
Furthermore, reclined seat positions also pose a challenge for the booster seat in its current design (*Figure 16*). Booster seats would also need design changes to adapt to a reclining position in the case this reclining functionality would be made accessible for booster seated children as well.

V. LIMITATIONS

The study was conducted in a static environment and no dynamic driving was included. The impact of the driving dynamics and of motion sickness when seated in different sitting configurations could not be taken into account. This study took also the hypothesis that the usage of short and long trips and the outer size of passenger vehicles do not fundamentally change.

VI.CONCLUSION

This explorative workshop proposes seating configurations which shall be further studied for crashworthiness both for adults and children.
The different novel seating configurations challenges can be covered by studying in addition to today's upright forward-facing vehicle seats following vehicle seat adjustments:

- Rearward-facing upright
- Forward-facing relax
- Rearward-facing relax
- Forward-facing – rotation up to 20° inboard and outboard
- Rearward-facing – rotation up to 20° inboard and outboard

Future child seats for automated driving vehicles shall offer a safe ride for children in those new conditions. Special care has to be taken to avoid that consumers will install rearward-facing child seats to rearward-facing vehicle seats. Face-to-face seating configurations will offer the opportunity to more children of all sizes to travel rearward-facing and therefore to travel in a safer way.

VII. ACKNOWLEDGEMENTS

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