# Older Children's Sitting Postures, Behaviour and Comfort Experience during Ride – A Comparison between an Integrated Booster Cushion and a High-Back Booster

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***Abstract*** Sitting postures and comfort experience were analysed from six children aged 7-9 (131-145 cm) seated on an Integrated Booster Cushion (IBC) and a high-back Booster (hbB) during 1 hour on-road drives, respectively. Data were collected from video recordings, questionnaires and interviews. When seated on the IBC the most frequent posture was with the entire back and shoulders against the seat back and the head upright. On the hbB, the shoulders were seldom against the backrest. The most frequent lateral sitting posture for both boosters was upright with the seat belt in contact with the neck or mid-shoulder. Moderate and extreme forward and lateral postures occurred occasionally. A positive attitude was found towards the IBC due to possibilities to move freely, the soft seat cushion and the absence of torso supports, but the short seat cushion created some inconvenience. The hbB was perceived hard, created a locked-in feeling and felt unpleasant due to movements when changing postures. The combination of objective and subjective measures provided valuable information regarding children's sitting behaviour. It is obvious that children do not always sit in on-road drives as in crash tests. Their activities and perceived discomfort influenced the selection of sitting posture and seat belt positions.

***Keywords*** sitting posture, integrated booster cushion, on-road drive, children, comfort

## I. INTRODUCTION

In the late 1970s belt-positioning boosters were introduced to allow a better geometry of the vehicle seat belt with respect to the child occupant [1]. Today, there are three main boosters: booster cushions, high-back boosters (including backrests) and integrated (vehicle built-in) booster cushions. The boosters are used with the vehicle's seat belt, which restrains both the child and the booster. The integrated booster cushion (IBC) was developed in order to simplify usage and to minimize misuse [2], then further developed to adjust to the growth of the child by providing two levels in height [3]. By using a booster the lap belt can be positioned over the thighs reducing the risk of abdominal injuries [4-5]. Also the booster helps to improve comfort of the legs, reduces slouching and encourages a better shoulder belt position. As a result of sitting higher up, a better view out of the window is accomplished for the child. Boosters have shown to improve protection in all types of crash situations [5-6].

Booster usage is recommended up to 10–12 years of age. In Europe, the law requires children shorter than 135 cm or 150 cm (depending on country) to be restrained in child restraints appropriate to their size. However, older children are not frequently using boosters; thus this age group (9–12 years) is more frequently injured than younger children (4–8 years) [7]. Reasons for non-usage of a booster include short trips, riding with friends and child refusal to use it [8]. Children perceive the booster as childish and parents motivate non-usage by claiming or suggesting inconvenience [9].

An on-road driving study [10] involving six young children 3–6 years old evaluated differences in sitting postures on high-back boosters with large (forward protruding) and small head side supports, respectively. The high-back booster with large head supports resulted more frequently in sitting postures with no shoulder to backrest contact and for both high-back boosters the children were seated with the head forward of the front of the head side supports for more than half of the ride. In a study with sleeping children it was shown that a

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high-back booster with head side supports offered support and thereby the shoulder belt remained on the shoulder to a larger extent compared to children seated on a booster with no head side supports or directly on the seat bench [11]. Another on-road driving study was performed [12] where natural sitting postures of children aged 8-13 (in the transition age from booster) were studied using a booster cushion (backless) and seat belt only. The results showed that the children sat with their upper back and shoulders in contact with the seat back independent of using a booster cushion or not. The booster cushion helped to position the belt at mid-shoulder, guide the lap belt below the abdomen in slouched postures and keep the children centralised and in a more stable lateral sitting posture.

Andersson et al. [10] and Jakobsson et al. [12] stated that comfort is an important aspect to consider when designing protection for children, which has a significant impact on sitting postures and thereby safety. However, there is not much information available neither about how children's activities during ride influence their sitting postures nor if perceived discomfort related to the design of the protection system affects their postures and physical movements over time.

Comfort is a subjective time-dependent experience (including physical, functional and psychological aspects) related to relaxation and defined as absence of any disturbing load [13]. Comfort is normally not possible to express in terms of more or less comfort, so the feeling of discomfort is instead the parameter measured [14-15]. Physical discomfort is an inappropriate physical loading and perceived from no inconvenience to extensive pain with a number of expressible feelings in between, such as various grades of muscular fatigue. Sitting discomfort of office chairs and car/truck seats has been studied using different objective and subjective methods [14,16-17], showing that subjective estimations of perceived discomfort are the most effective and reliable measures to use.

The on-road driving studies with children presented so far [10-12, 18] have added valuable knowledge for future safety improvements. However no study has so far focused the older children riding in different types of boosters. Hence, the objective of this study was to identify sitting postures and seat belt positions of children in the older age range of booster usage when seated on two very different types of booster, during on-road rides in the rear seat of a passenger car. The two boosters were one integrated booster cushion, built into the vehicle seat, and one high-back booster using no attachment except the seat belt restrained together with the child. Also, the children's behaviour, activities during ride and comfort experience over time were studied to get a deeper understanding of their choice of sitting postures, providing knowledge for improvement of comfort and safety aspects for protection of children in cars.

## II. METHODS

In this study a combination of objective and subjective measures were used. Objective data were collected regarding sitting postures, seat belt positions and activities during ride. Subjective data were collected regarding perceived discomfort and attitudes towards the protection systems tested (boosters and seat belts in combination). Activities and discomfort feelings were registered to get an understanding of whether these affected the children's choices of sitting postures.

### Test subjects

Six children between 7-9 years old (131-145 cm), 4 boys and 2 girls participated in the study. The children were recruited based on their age and stature by contacts within the area of Gothenburg, Sweden. The selection criterion was to include children with a stature of 135-150 cm, being the upper range before transition from booster to seat belt only. The demographics for the children included in the study are shown in Table I. Sitting height was defined as the floor to top of head distance when seated with a straight back, and both feet on the ground.

TABLE I

DEMOGRAPHICS OF THE CHILDREN AND THE STAGE OF THE IBC (HIGH OR LOW). THE CHILDREN WHO BEGAN THE STUDY WITH THE IBC ARE INDICATED WITH GREY.

| Child | Gender | Age (years) | Weight (kg) | Stature (cm) | Sitting height (cm) | IBC-stage |
|---|---|---|---|---|---|---|
| 1 | Girl | 9 | 35 | 145 | 75 | Low |
| 2 | Boy | 8 | 30 | 134 | 73 | Low |
| 3 | Girl | 9 | 31 | 140 | 73 | Low |
| 4 | Boy | 8 | 28 | 131 | 70 | High |
| 5 | Boy | 7 | 32 | 138 | 74 | Low |
| 6 | Boy | 7 | 30 | 133 | 71 | High |

**Test setup**

Each child made two rides in the rear seat in a Volvo V60 passenger car, model year 2011. The child was positioned in the outer right position and tested two types of belt-positioning boosters: the IBC and the hbB (Figure 1). The hbB model was a Volvo booster, similar to Britax Kid Plus, a commonly used hbB in Sweden. This booster does not have any additional attachments, such as attachments to the ISOfix/LATCH or top tether vehicle anchorages. The IBC was a built-in booster available in Volvo V60 and adjustable in two stages (heights) to accommodate the growing child [3]. In this study the IBC was adjusted according to the stature of the child; children shorter than 134 cm used the highest stage (Table I). The test order of the two boosters was alternated equally between the test subjects: Children 2, 4 and 5 started with the IBC and Children 1, 3 and 6 with the hbB (Table I). The child was restrained together with the booster by the vehicle's lap and shoulder belt.

The child's parent drove the car and no other passenger was present in the car. The pre-determined test route took about one hour and included city traffic (25%) and motorway drive (75%).

Prior to the test, the parent and the child were informed about the test procedure. The instructions were to behave as normal as possible during the ride, except refrain from eating. This meant they could do any activity they normally did when traveling in a car but no activities were given as examples of what they were allowed to do. The children wore tight long-sleeved white shirts to serve as good contrast during the video recordings. The IBC was set to fit the stature of the child before entering the car. The children put on the seat belt themselves, but the test leader ensured proper restraint use before the drive. When the two test sessions were ended the child received two movie tickets and the parent received gift vouchers of 500 SEK (approximately €50) as compensation for participating in the study.

Fig. 1. The integrated Booster Cushion (IBC) and the high-back Booster (hbB) used in the tests.

**Objective data collection**

Objective data regarding the children's sitting postures, seat belt positions and activities during ride were collected through observations using four video cameras mounted inside the car. The cameras provided a front view of the child, a perpendicular lateral view of the child, an oblique view of the child and a forward view of the road.

In the analysis the children's activities were divided into three categories: (1) filling out the questionnaire, (2) using an electronic device (like a smart phone) or playing with something (for example, a sticker book), and (3) other activities where no toys/devices were involved. Also the duration of each activity was quantified.

The children's sagittal and lateral sitting postures in the two boosters were defined using specific classification systems. Also the duration of each sitting posture was quantified. Likewise, the shoulder belt position relative to the shoulder was classified as well as the duration of each belt position.

*Classification of sagittal and lateral sitting postures*

A number of head and torso positions were defined for analysis of sagittal and lateral sitting postures. The system was derived from sitting posture categories defined in prior studies [13, 15, 19]. The sitting postures were systematized by differentiating the sagittal (fore to aft) from the lateral sitting postures (left to right).

The sagittal torso postures for both boosters were defined as: 'a' the entire back including shoulders against the backrest, 'b' the entire back but not the shoulders against the backrest, 'c' the child remains upright or leaning slightly forward but no part of the back against the backrest, 'd' the torso is leaning forward without contact with the backrest, and 'e' the child sits in a slouched posture, i.e. the upper back including shoulders against the backrest but no contact between the lower back and backrest. The sagittal head postures were defined as: 'a' head against the backrest/head restraint, 'b' head upright relative to the torso, and 'c' head leaning forward relative to the torso. The torso and head postures were combined to form the sagittal sitting postures; for example, in the 'ab' posture the child sits with the entire back against the backrest, while the head is upright (Figure 4b).

The lateral sitting postures for the IBC were classified in three different categories (Figure 2): 'a' the torso in an upright posture (Figures 2a-b), 'b' the torso in a slightly tilted posture (the shoulders are within the outer lines) (Figures 2c-d), and 'c' the torso in a substantially tilted posture (the shoulder is outside the outer line) (Figure 2e).

The lateral torso postures for the hbB were defined as: 'a' the whole torso is within the side supports, 'b' the torso is leaning towards the side support and one shoulder is very close to, or slightly outside, the edge of the side support, and 'c' the shoulder (and parts of the torso) is clearly outside the side support. The lateral head postures were defined as: 'a' between the side supports, 'b' resting against one of the head side supports (or a slightly lateral posture of the head when the upper body is leaning forward), 'c' partly outside the head side supports, and 'd' completely outside the head side supports.

For both the IBC and the hbB the direction of the lateral movement was indicated by plus (+) when leaning inboard, and by minus (-) when leaning towards the side window (outboard).


Fig. 2. Definitions of lateral sitting postures when seated on the IBC and shoulder belt positions a) upright posture and shoulder belt against the neck b) upright posture and shoulder belt on the mid-shoulder c) slight tilting posture and shoulder belt on the edge of the shoulder d) slight tilting posture and shoulder belt off the shoulder e) substantial tilting.

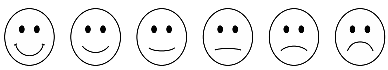
*Coding of the shoulder belt position*

The shoulder belt position for both boosters was coded in four categories (Figures 2a-d); the shoulder belt against the neck, mid-shoulder, edge of the shoulder and off the shoulder. This applied for both boosters.

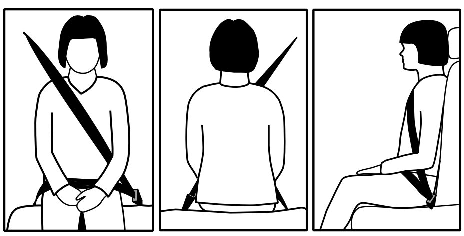
**Subjective data collection**

Subjective data were collected through questionnaires filled in every 20 minutes during each drive; in total six questionnaires were collected from each child. The questionnaires dealt with perceived discomfort and discomfort changes over time caused by the booster and the seat belt. The ratings contained three tasks: (1) a 6-level scale with figures of various emotional facial expressions, (2) colouring of potential inconvenience on figures of a seated child, and (3) a word association task where the child should choose between contradicting words related to emotions (Figure 3). The position of the positive and negative values of the contradicting words was randomized to minimize the risk that the design of the task would influence the children's choices.

Task 1



Task 2



Task 3

1. Good – Bad
2. Safe – Insecure
3. Silly – Cool
4. Soft – Hard
5. Tensed – Relaxed
6. Feels as usual – Feels unusual
7. Comfortable – Uncomfortable
8. Loose – Locked in

Fig. 3. The three subjective data collection instruments regarding discomfort

When the first test drive was completed a semi-structured interview was made with the child regarding comfort experience of the tested booster. The child answered questions about the general comfort of the booster and its different parts, i.e. the cushion and the backrest, as well as the seat belt, but also questions about inconvenience, feeling of safety and ability to move freely. Since the interview was semi-structured, many of the questions were based on alternatives. For example, when the children were asked if they felt safe the children could choose between: *not at all, a little, rather much* and *very much*. To fully understand the answers, the probing question 'why' was always used as a follow-up question. The same interview questions were then given after the second drive, together with additional questions comparing the two boosters tested. Also the child's habits related to booster and restraint usage in general were discussed and possible improvements of the tested boosters. Finally the parent was asked what the child usually did during car riding and if the child had acted different during the tests compared to a normal situation. The interviews with the children were held with the parent present, but the interviewer focused on the child and avoided any interference from the parent.

## III. RESULTS

**Objective results**

*Sagittal sitting postures*

Figure A1 (in Appendix) shows the means of the total ride duration regarding sagittal sitting postures in both boosters for all six children. The large standard deviations indicate that there are substantial individual differences. When seated on the IBC, the most frequent torso sagittal posture for all children, apart from Child 2, was with the entire back and shoulders (torso position 'a') against the seat back (in average 72% of the total ride duration) (Figures 4a-c). Child 2 spent most of the time in a slouched posture with no contact between the lower part of his back and the seat back. The most frequent head posture in the IBC was upright (48%) followed by the head leaning forward (37%) relative to the torso, and the head in contact with the seat back (15%) (Figures 4a-c). Child 5 leaned the head forward relative to the torso due to using an electronic device during the majority of the trip.

When seated on the hbB the children spent less time sitting with the upper back and shoulders in contact with the backrest compared to the IBC. The most frequent torso posture (34%) was with the entire back but not the shoulders against the backrest (torso position 'b') (Figures 5a-b) followed by slouched posture (29%) (torso position 'e') (Figure 5c) and contact with the entire back (28%) (torso position 'a'). The remaining time the children were leaning forward to various extents. The most frequent head position was upright in relation to the torso (42%) (Figure 5a), which was slightly more than leaning forward (36%) (Figure 5b), followed by the head in contact with the backrest (22%) (Figure 5c). The individual variation among the children when seated on the hbB was greater than when seated on the IBC. Considering the mean values of the combination of torso and head postures the most frequent posture when seated on the hbB was with the entire back but not the shoulders against the backrest and the head leaning forward.

In total, four of the children assumed a slouched posture during ride on the IBC and five children on the hbB. The time the children spent in a slouched posture was 12% and 29% on the IBC and the hbB, respectively. It was mainly Children 2 and 4 who assumed a slouched posture on the IBC; Child 2 slouched for 48% of the ride and Child 5 for 18%. Child 2 also slouched 80% when seated on the hbB (Figure 5c).


Fig. 4a-c. Examples of postures (left to right) with the entire back and shoulders against the seat back and head posture a) in contact with the seat back, b) upright, and c) leaning forward.


Fig. 5a-c. Examples of postures (left to right) with the entire back but not the shoulders in contact with the backrest and a) head posture upright, b) head posture leaning forward, and c) slouched torso posture and head posture in contact with backrest.

*Lateral sitting postures and belt position*

When seated on the IBC, the most common lateral posture of the torso was categorised as upright (78%) (Figures 2a-b; Figure A2); the second most common posture varied among the children. Five of the six children (except Child 5) sometimes leaned the lower arm, elbow and/or the head towards the door panel, especially Child 1 (11% of the time), which sometimes resulted in a slight or substantial outboard tilting of the torso. In total, an outboard tilting posture was recorded during 4% of the time. An inboard tilting often occurred as the child was reaching for something lying on the seat cushion next to him/her, interacting with the parent in the driver seat, or looking out through the front, left or rear windows. In total, an inboard tilting was registered during 7% of the time. Occasionally Children 4 and 6 rotated the whole body, including the legs, inboard as well as outboard up to 90 degrees around the z-axis.

The most common seat belt position on the IBC was either close to the neck (60%) or on the mid-shoulder (24%) (Figure 2b; Figure A3). However, Children 2 and 6 occasionally had the seat belt positioned far out on the shoulder (on average 24%), or off the shoulder (on average 6%). Child 6 had the shoulder belt positioned under his arm during almost one minute.

When seated on the hbB, the most common lateral posture of the torso among the children was in between the side supports (74%) followed by slight (20%) or substantial inboard tilting (4%), while outboard tilting was uncommon (2%) (Figure A2). The lateral posture of the head was dominated by no (34%), slight (38%) or large (15%) inboard displacements. Child 5 leaned the arm towards the door panel while seated on the hbB, and he was the only child that did not lean the arm towards the door panel on the IBC. Children 4 and 6 tended to rotate the whole body around the z-axis on the IBC while they did not show these tendencies on the hbB. Sometimes the children adapted a slightly rotated posture when relaxing (Figure 6a), or in order to increase the space around the arms while, for example, playing (Figure 6b) or writing. Child 6 fell asleep during the last ten minutes of the ride, leaning his head against the right side support (Figure 6a). No other children fell asleep. Five of the children (except Child 2) indicated some discomfort at the lower part of the back (Figure 6c).

TABLE II

THE DISTRIBUTION OF ACTIVITY DURATIONS SHOWN AS A PERCENTAGE OF THE TOTAL RIDE. THE BOOSTER THE CHILD STARTED TO TEST IS SHOWN IN GREY.

| Child | Booster | 1 | 2 | 3 | Total |
|---|---|---|---|---|---|
| 1 | IBC | 22% | 0% | 78% | 100% |
| | hbB | 10% | 31% | 59% | 100% |
| 2 | IBC | 5% | 47% | 48% | 100% |
| | hbB | 17% | 66% | 16% | 100% |
| 3 | IBC | 22% | 0% | 78% | 100% |
| | hbB | 23% | 0% | 77% | 100% |
| 4 | IBC | 23% | 0% | 77% | 100% |
| | hbB | 22% | 74% | 4% | 100% |
| 5 | IBC | 21% | 77% | 2% | 100% |
| | hbB | 12% | 51% | 37% | 100% |
| 6 | IBC | 16% | 23% | 62% | 100% |
| | hbB | 12% | 0% | 88% | 100% |

*(**1**) filling out the questionnaire, (**2**) using an electronic device/playing with something, (**3**) other activities*

The most common positions of the seat belt on the hbB were either close to the neck (42%) or on the mid-shoulder (56%) (Figure A3). In contrast to the results found on the IBC, Children 4 and 6 had the seat belt positioned close to the neck (22%) or on the mid-shoulder (74%), i.e. they had the seat belt to a less extent far out on the shoulder (5%). Five of the children (except child 6) moved the belt away from the neck and further out on the shoulder during the ride.

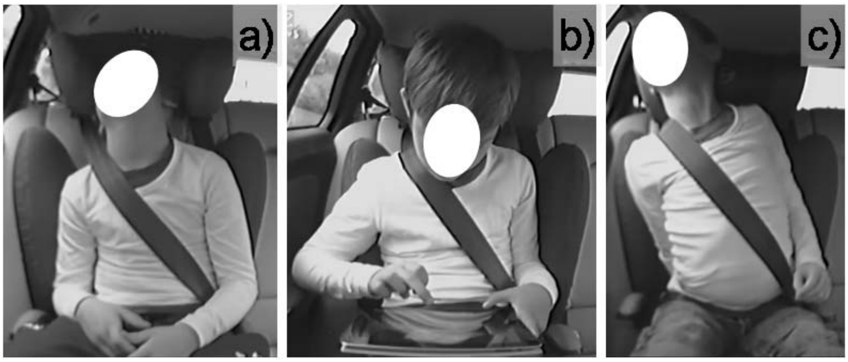


Fig. 6a-c. a) The posture (Child 6) while sleeping b) A slightly rotated posture (Child 5) while playing c) Indication of some discomfort at the lower part of the back (Child 4).

*Children's activities during ride*

The children's activities during ride showed a large variety as to both extent and content. Examples of activities apart from filling out the questionnaire were playing on a smart phone, looking at video/photos on an electronic device, taking photos, sorting small toys/things and using a sticker book. Examples of other activities not including a device or toy were fixing the hair, talking to the driver, playing with the grab handle above the door or playing with the seat belt.

As the children were filling out the questionnaire, they often used their thighs as writing support resulting in a forward flexed posture. If the time the children filled out the questionnaire was excluded from the analysis, a decrease in the forward leaning head posture of 6% on the IBC and 9% on the hbB was seen. The time the children spent filling out the questionnaires was on average 18% and 16% for the IBC and the hbB, respectively.

The durations of activity in percentage (divided into filling out the questionnaire, using an electronic device/playing with something and other activities) of the total ride for the IBC and the hbB are shown in Table II. When seated on the IBC Child 2 started to use a smart phone after half the trip and played until the trip ended. During the first half of the ride he changed sagittal sitting posture 5 times more often than during the second part of the ride.

**Subjective results**

The subjective assessment of perceived discomfort and attitude towards the boosters (including the three tasks in the questionnaire and the interview) generated the following results.

*Task 1: 6-level scale with figures of facial expressions*

In Table III the change in the overall impression of the booster tested is presented. The children's assessments were more positive for the IBC than for the hbB. The children who did not start with the IBC (Children 1, 3 and 6, Table III) assessed the IBC on the happiest level during the whole ride. This was also the case for Child 4 who started with the IBC. The variation in the assessments was greater for the hbB than for the IBC. For the hbB, five of the six facial expressions possible were used, varying between the children and for three of the children also between the times for assessments.

TABLE III
RESULT FROM TASK 1, WHERE 1 CORRESPONDS TO THE HAPPIEST FACIAL EXPRESSION AND 6 TO THE MOST SAD EXPRESSION. THE CHILDREN WHO STARTED TO TEST THE IBC ARE INDICATED WITH GREY.

| | **IBC** | | | **hbB** | | |
|---|---|---|---|---|---|---|
| Elapsed time | 20 min | 40 min | 60 min | 20 min | 40 min | 60 min |
| Child 1 | 1 | 1 | 1 | 3 | 1 | 4 |
| Child 2 | 1 | 2 | 1 | 1 | 2 | 2 |
| Child 3 | 1 | 1 | 1 | 2 | 2 | 2 |
| Child 4 | 1 | 1 | 1 | 3 | 6 | 6 |
| Child 5 | 2 | 2 | 2 | 3 | 3 | 3 |
| Child 6 | 1 | 1 | 1 | 3 | 3 | 3 |

*Task 2: Colouring of inconvenience on a seated child*

The result from the children's colour markings confirmed and specified the result from task 1 that the hbB was perceived as more uncomfortable. Figure 7 shows a discomfort mapping compilation of which body areas the children said were exposed to discomfort during ride on the two boosters respectively. When seated on the IBC a few children felt discomfort at the front and the back of the neck or at their bottoms. One child marked discomfort on the calves in the last assessment of the IBC. Besides that, no other areas were marked. When seated on the hbB several children marked the entire back and neck, the front shoulder and neck as well as the arms.

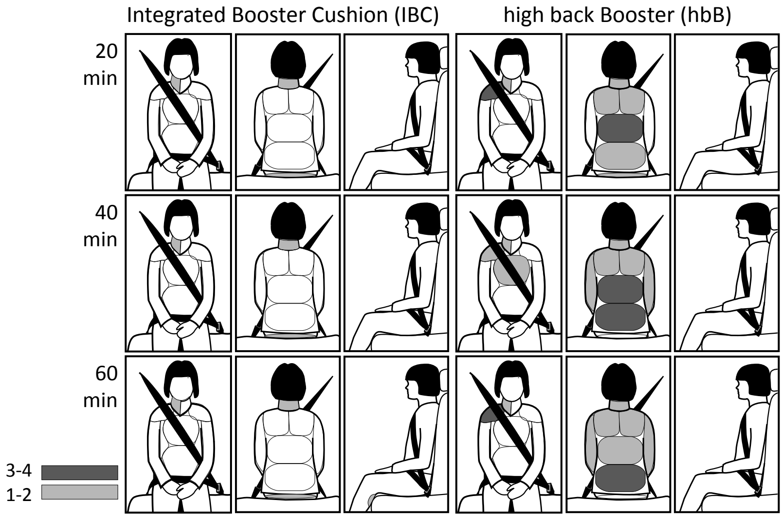



Fig. 7. The children's markings of inconvenience when seated on the IBC and the hbB respectively. Light grey colour represents that 1 to 2 children marked the area. Dark grey represents that 3 or 4 children marked the area.

*Task 3, Word association*

The result of the word association task is shown in Figure 8 and presents what percentages of the children who selected the positive words for the IBC and the hbB, respectively. In general, more positive words were chosen when the children were seated on the IBC, both when assessing the experience of the interaction with the booster and the interaction with the seat belt. The children were always using both a booster and the seat belt. When selecting between the words 'feeling safe or insecure' 90 % of the children associated both the boosters with safety. For the hbB 80% of the markings were set on the negative alternative *unusual* when asked about how it felt to travel seated on the booster.

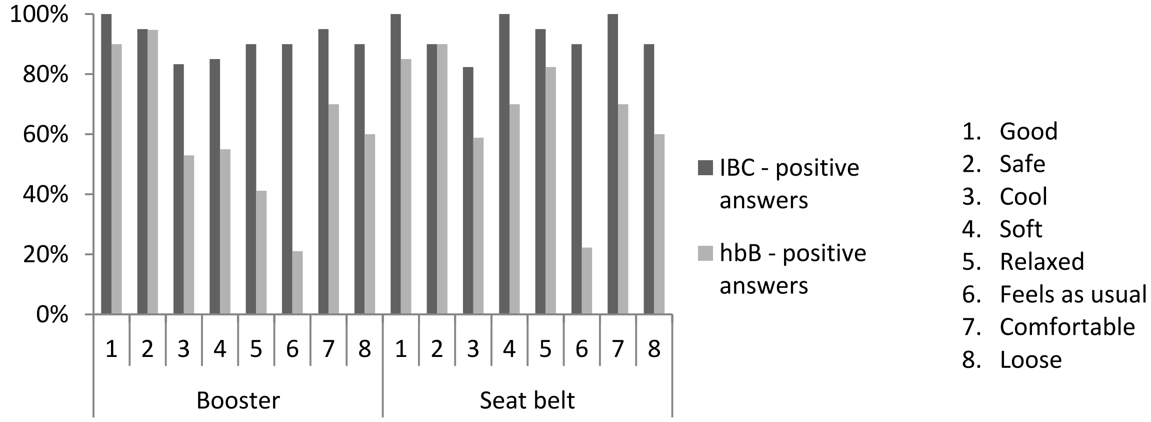



Fig. 8. Results regarding positive response from the word association task for the boosters tested. The perception from the interaction with the booster and the seat belt is shown separately.

*Interview*

All six children preferred the IBC when comparing the two boosters. Five children also said they would like to have this type of booster in their own car. No child favoured the hbB. When the children had to choose between the two boosters tested, the booster they normally used, or no booster at all, Children 2, 5 and 6 stated they preferred their own booster (which was a backless booster). Child 1 wanted no booster at all (as she normally travelled) and Children 3 and 4 preferred the IBC.

In general the interview results regarding discomfort showed that the IBC was assessed more positively than the hbB by all children due to possibilities to move freely, the absence of torso supports and the simplicity of the design. The most shared comment was that the IBC was softer to sit on than the hbB. The length of the IBC booster seat cushion created discomfort for two children, whereof one suggested a longer seat as an improvement. The backrest of the hbB was perceived as uncomfortable and the whole booster was perceived as hard. Most children disliked the side wings on the hbB since they created a restrained and locked-in feeling and prevented them from looking out through the side window. One child imagined that the wings were good to lean against if sleeping. It was also found unpleasant that the hbB moved when the car was turning or when the child moved its upper body. As improvements for the hbB the children desired a softer booster cushion and backrest as well as a wider backrest.

## IV. DISCUSSION

In the case of a crash the sitting posture of a child could influence his/her protection. Optimally a child should be positioned laterally upright, with its back and head close to the seat back and head restraint. The lap belt should be positioned over the thighs and the shoulder belt positioned on the mid-shoulder or closer to the neck. This is how the crash test dummies are positioned when evaluating crash performance of different child restraint systems [20]. However, it is obvious that children do not always sit like the crash test dummies, which means that the protection can be affected. Children move naturally and their sitting postures are influenced by many situational factors such as type of protection used, activities and perceived discomfort.

The present study provides insight into how children in the older age range (7-9 years, 131-145 cm) of booster usage sit under normal circumstances in the rear seat during on-road car riding. It also includes information on their perceived discomfort over time and how different activities influence their postures. The subjective as well as the objective results provide helpful input for improvement of comfort aspects in the development of boosters for children of the older age group of booster usage. Improved comfort will have positive influence on protection enabling a more controlled sitting posture during riding in the car.

### Sitting postures, seat belt positions and activities

The summarised results show that the children do not sit like crash test dummies. The children frequently changed postures during the ride and kept themselves busy with a number of activities nearly all the time. Some posture changes were also due to discomfort caused by the protective systems. The various activities (e.g. reaching for things, playing with devices, looking through the windows, interacting with the driver) contributed highly to their choice of sitting postures. The duration of some activities were short, such as talking to the driver and reaching for things, but others, such as playing with electronic devices, were performed during longer periods of time. Playing often resulted in a concentrated forward flexed sitting posture with low frequency in posture changes, with the head leaned forward, which might not be the optimal sitting posture during a crash. However, when the children did not entertain themselves they often stayed in more appropriate sitting postures from a safety perspective, especially when seated on the IBC, which did not create much discomfort due to its simple design.

In general a more upright sitting posture was chosen when seated on the IBC; i.e. with the upper back and shoulders in contact with the seat back and the head upright. When seated on the hbB the most frequent posture was with the back but not the shoulders against the backrest and the head leaning forward. Slouching was more common in the hbB compared to the IBC. Extensive forward leaning postures occurred on average 4% of the time on the IBC and 6% on the hbB. This was a result of the child interacting with the driver or reaching after something. However, when the children filled out the questionnaire they often used their thighs as writing support and thereby leaned forward. When seated on the IBC the variation in sagittal sitting postures between the children was smaller as compared to the hbB. No major difference was seen in how frequently they changed sagittal sitting postures; the mean values were 132 times and 142 times for the IBC and the hbB, respectively.

The chosen lateral sitting postures were influenced by the activities performed and the design of the boosters, e.g. the hbB was seen to prevent outboard tilting due to the side support. The most common lateral sitting posture of the children's torso was upright for both the IBC and the hbB. Further, inboard tilting was more common than outboard tilting on both boosters, and it may have been a way of avoiding the shoulder belt chafing to the neck. Moreover, since the shoulder belt was positioned on the outboard shoulder it may have been more preferable to tilt inboard than outboard. Outboard tilting was more common on the IBC; five of the six children sometimes leaned the lower arm, elbow and/or the head towards the door panel. In contrast, only one child leaned the arm against the door panel when seated on the hbB.

Children 4 and 6, who were seated on the higher stage on the IBC, rested their feet on the adult cushion base as shown in Figure 4b. They also tended to rotate the whole body around the z-axis, both inboard and outboard. Furthermore, they had the seat belt positioned further away from the neck and closer to the shoulder, and occasionally even off the shoulder. Child 6 even had the seat belt positioned under his arm for almost one minute. All these activities might have an intentional or unintentional purpose to achieve a more comfortable sitting posture. The children who were seated on the lower stage of the IBC were trying to find foot support by putting the right foot on the floor panel below the door and the left foot on the centre panel in front of the mid seat position in the rear seat. This shows that support for the feet, which can be used occasionally to decrease discomfort, could improve overall comfort.

The children were seated with the upper arms along the sides of the torso or slightly angled forward relative to the torso (Figure 4b) during a majority of the ride, regardless of whether they were playing with something or had their hands resting in the lap. The more extreme upper arm positions, i.e. when the upper arms were more than 90 degrees angled from the torso in the sagittal plane, were found for shorter periods of time. When this happened the children were for example interacting with the driver and pointing at something, fixing their hair or playing with the grab handle above the door.

When seated on the IBC the children could move around more freely. Thereby the belt was off the mid-shoulder position more frequently than when seated on the hbB, where the design of the high-back to some extent counteracted belt displacements. The belt positions with the shoulder belt far out on the shoulder or off the shoulder were 11% when seated on the IBC and less than 3% on the hbB. There were two children seated on the IBC who frequently had the belt in these positions (Child 4 24% and Child 6 36% of the riding time). These children also moved around more on the IBC compared to the others. They were the shortest in the test group and seated on the higher stage of the IBC and also the two who used the adult cushion base (Figure 4b) as foot support. On the hbB the belt was guided on the shoulder by the upper guiding loop and the child was restricted by the torso side supports. When the children leaned forward, the shoulder belt stayed in the same position.

**Comfort experience of the tested boosters**

The combined result from the questionnaires, interviews and also from the children's body language and behaviour seen on the video recordings showed that the children experienced more discomfort when seated on the hbB than on the IBC.

The body area where most children perceived inconvenience when seated on both boosters (Figure 7) was around the front and the back of the neck. This was the area where the seat belt was situated. Also on the video recordings it was seen that the children moved the seat belt away from the neck now and then when seated on both boosters, which is a sign of discomfort. However, more children felt inconvenience at the neck and shoulder areas when seated on the hbB than on the IBC, probably due to the fact that the child was more locked in an upright position by the side wings on the hbB.

When seated on the hbB the entire back and arms were inconveniently affected for several children. This was confirmed by the interviews where the children stated that the backrest of the hbB was hard to lean against and the torso side supports were found too narrow to fit in-between. Also the video recordings showed that the children seemed to be annoyed by the backrest; they lent forward, turned around and touched the lower part of the backrest, pushing the shoulders and head against the backrest and the lower part of the back forward.

The perceived discomfort did not increase much over time in this study (Figure 7). Except for the neck and back that were affected during the whole ride, only one or two children felt inconvenience from bottoms, calves or arms at the later part of the ride. If a longer trip than one hour had been performed, the discomfort might have intensified and also other body areas than to the neck and back may have been uncomfortably loaded for more children. Several studies regarding sitting discomfort in vehicles for adults have shown an increase in perceived discomfort after 1-1.5 hours. After 2-3 hours of sitting, muscular fatigue as well as pain was experienced in the back, shoulders, neck, legs and feet [14, 17]. Increased discomfort by number of driving hours was also shown on video recordings by intensification of movements and changes of sitting postures for car and truck drivers [17, 19]. Since children usually are more restless than adults, they might change postures more rapidly and more often than adults. It was also seen on the video recordings in this study that the children changed postures often during a ride of one hour. However, the causes for posture changes are probably due both to discomfort and activities. To get more insight into how discomfort affects children's behaviour over time, on-road drive studies of 2-3 hours need to be performed.

The children's attitudes towards the boosters appeared to depend much on perceived discomfort but also on visual impression, recognition and earlier experience. This age group (7-9 years) needs a booster to be suitably restrained; therefore it is essential to offer them a booster with good comfort in order to continue the usage until they can be properly restrained with a seat belt alone. When choosing which booster they preferred all children favoured the IBC, which was the least uncomfortable of the two boosters tested and also got most positive ratings in the emotional word association task (Figure 8). The majority of the children stated that it felt unusual to travel in the hbB. A shared comment when the children saw the hbB was; 'I used a booster like that when I was younger' or 'my little sister/brother uses a booster like that'. Although it was only one child in this study who did not normally use a booster at home, the result indicated that these children in the older age group of booster usage preferred not to use a booster at all. Often children would like to feel grown up and thereby use a seat belt only [9]. Osvalder et al. [21] showed that the frequency of usage of this type of restraint among older children is poor, but essential to reduce injuries.

It is interesting to highlight that the children perceived both boosters (together with the seat belt) as safe (Figure 8), in spite of the fact that they rated the IBC with more positive words than the hbB for all other contradicting words in task 3. This probably has to do with attitudes as children often knew they travel safe in cars if they are using a child restraint system proposed by parents or adults, independent of which system it is. This was also shown in Bohman et al. [9], where children in the age of 7-8 years stated that riding in a child restraint was very important for safety and that their parents wanted them to use it.

**Study design**

In this study objective data regarding sitting postures, seat belt positions and activities were supported by subjective data regarding discomfort issues and attitudes, which provided possibilities to interpret and compare the results deeper. When analysing the results the children's behaviour in the car corresponded in most cases to the answers they presented in the questionnaires and interviews. However, sometimes it was impossible to understand from only analysing the video recordings that the child experienced things they described in the interviews. Therefore it is an advantage to use both objective and subjective measures in order to get increased knowledge about why children sit and behave as they do during ride.

The objective data obtained from the four video cameras provided qualitative data. The classification scales developed for analysing sagittal and lateral postures worked well, which also was shown by Jakobsson et al. [12] for sagittal postures. However, some difficulties arose when analysing the contact between the child and the backrest of the hbB due to the torso support. Also some difficulties occurred for both boosters when determining the exact lateral posture relative to the backrest/seat back when the children were leaning forward, since small lateral movements appeared to be larger when the child was closer to the camera (distortion). The video recordings did not show any signs that the cameras seemed to affect the children's behaviour during ride. When they entered the car, they were told about the cameras, and at that time a few children made a face towards them, but then ignored them.

The use of questionnaires to fill out during ride influenced the children's sitting postures more than expected. The instruction was to fill out the questionnaire every 20 minutes but no further instructions where given how to handle it. The time the children used to fill out the questionnaire varied between the children and the different occasions (Table 2), where the mean value was 18% and 16% of the riding time for the IBC and the hbB, respectively. Many children held the questionnaire in their lap during the ride, which might have influenced their sitting posture to a minor extent. An idea for improvement is that the driving parent stops and hands over the questionnaire at pre-determined occasions, or that the child puts the questionnaire away on the seat every time it has been filled out. A support plate would also be a useful tool for the child when filling out the questionnaires.

To allow the children to act as they normally do when traveling in cars (except eating) made this study more realistic. The results showed a large variation in activities and most children were entertained with different tasks most of the riding time. Many children were using electronic devices to play with, which are products that did not exist some years ago. All parents said that their child had acted as normal during the rides and the activities performed were the same as the child normally did, except filling out the questionnaires. In future on-road studies with children it is most important that activities are included and, if the drives are longer than one hour, eating might be allowed too.

Traffic circumstances and driver mistakes in following the route affected the duration of the riding time to a minor extent, not more than 5-10 minutes. But since the proportions of city traffic and highway driving were approximately the same for all children these small differences did not affect the results.

The age range of the children included in the study did not affect the objective data collection, but when using subjective measures age and maturity are important factors. To achieve as trustworthy subjective results as possible, the design of the questionnaire and interview was made to fit the abilities of the tested age group regarding interpretation and response. Experience from earlier studies [9-10, 12, 20-21] and on-going studies with children in Sweden regarding protection in cars shows that children below 7 years of age sometimes can be too immature and might have difficulties to state their actual views, and also to express their feelings orally. Therefore a scale showing emotional facial expressions and colouring inconvenience on figures are tools that might help to get more reliable results. Also using follow up questions in interviews is helpful to get a better picture of what a child actually feels. An important factor when performing subjective assessments is also to be aware of the fact that people have different reference frames. In this study, one child considered a 'normal state' as very good, while another child considered a 'normal state' as either good or bad. Therefore 'why'-questions were asked after the alternative-questions to improve the understanding of the results. However, in spite of the attempt to form the subjective measures to fit the age of the children included in this study, one 8-year old child had some difficulties to understand and answer the questions properly.

The two types of boosters evaluated were chosen to be as different as possible from each other; the IBC being rigidly attached to the vehicle seat, with no lateral supports more than what the vehicle seat provides, and the hbB which is one of the largest on the market, providing side support and having no extra attachments to the vehicle than what is provided by the seat belt when the child is restrained. Obviously, the conclusions drawn in this study applies to these two types of boosters. Other types of boosters, such as an hbB which is attached to the ISOfix vehicle anchorages most likely would result in another combination of both subjective and objective results.

## V. CONCLUSIONS

This study provides an evaluation of how children of the upper size of child restraint usage sit and behave during on-road drives, riding on an integrated booster cushion (IBC) and high-back booster (hbB), respectively. The study confirms prior studies that children do not always sit like crash test dummies in the standardized crash test positions. Both the children's activities as well as perceived discomfort influenced the selection of sitting postures, including seat belt positions as well as motion behaviour during ride.

When seated on the IBC the children frequently adapted a posture with the entire back and shoulders in contact with the seat back and with the head in an upright position. While on the hbB their shoulders were not against the backrest. The most frequent lateral posture when seated on either booster was upright with the seat belt in contact with the neck or mid-shoulder. Moderate and extreme forward and lateral sitting postures occurred occasionally on both boosters due to activities and discomfort mostly created by the seat belt. Inboard and outboard tilting was to some extent prevented by the side supports of the hbB.

The attitudes regarding the IBC were positive and it was perceived as comfortable due to possibilities to move freely, which provided potential to change sitting postures, but it was also easier to perform outboard leaning. The soft cushion and the absence of torso supports were appreciated, but the short booster cushion and the absence of foot support when seated on the lower stage created some inconvenience.

The hbB was perceived hard and created a feeling of locked-in due to the side supports. The backrest caused inconvenience in the entire back, neck and arms. Also the movements of the booster when changing posture or when the car was turning were found unpleasant.

The combination of objective data collection from video recordings for evaluation of sitting postures, seat belt positions and activities together with subjective estimations and interviews regarding perceived discomfort and attitudes provided a valuable set of information regarding children's behaviour and experiences during on-road drive. The results from this study provide helpful input for improvement of safety and comfort aspects in the development of boosters for children of the older age group of booster usage.

## VI. ACKNOWLEDGEMENT

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## VIII. APPENDIX A

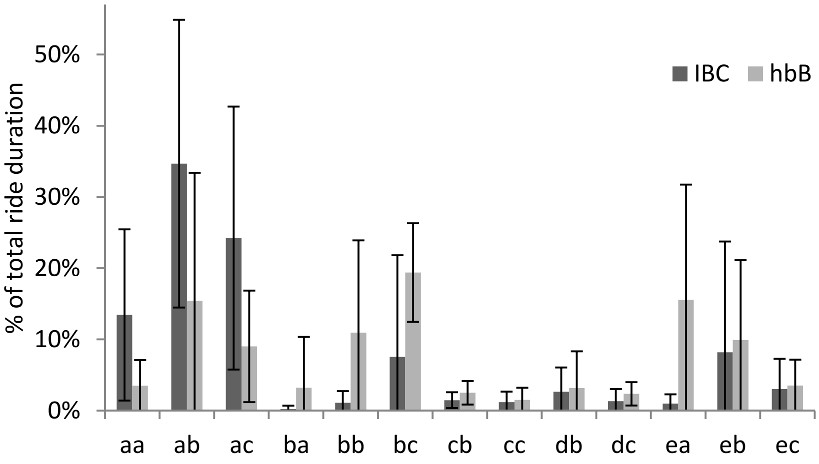


Fig. A1. The distribution of sagittal sitting posture durations shown as a percentage of the total ride duration. The mean and standard deviation for all 6 children presented by restraint type.

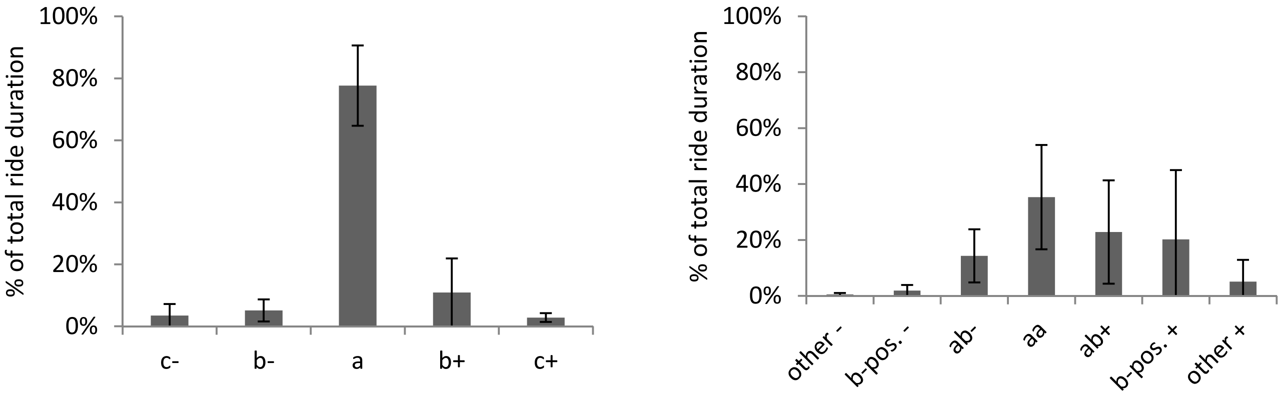


Fig. A2. The distribution of lateral sitting postures durations, shown as a percentage of the total ride duration. The mean and standard deviation of all 6 children presented by restraint type (the IBC – left, the hbB – right).

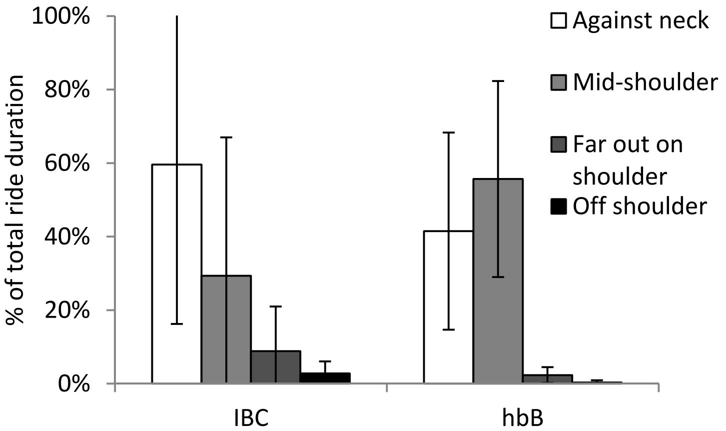


Fig. A3. The distribution of shoulder belt position durations, shown as a percentage of the total ride duration. The mean and standard deviation of all 6 children presented by restraint type.