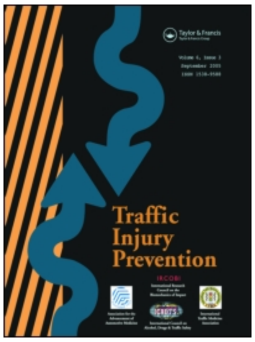

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A novel method for quanitifying comfort in child passengers demonstrates an association between child restraint comfort and errors in use of booster seats

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ABSTRACT

Objective: Misuse of child restraint systems is a widespread and long-standing problem impacting risk of injury and death in car crashes. Discomfort has been suggested as a causative factor for misuse, particularly in errors introduced by children while they use the restraints. However, the relationship between comfort and errors in use has never been studied. In this study we examine the reliability and sensitivity of a newly developed observational method for assessing comfort in children in vehicles. We then use this method to examine the relationship between comfort and errors in use of booster seats.

Methods: A novel method was developed for assessing comfort by counting fidgeting and postural adjustment behaviors to derive a Discomfort Avoidance Behavior (DAB) score. The sensitivity of the DAB score was examined by observing children in four different seating conditions designed as "comfortable" and "uncomfortable" (Part 1). Paired-samples *t*-tests were used to compare differences in DAB between seating conditions. The reliability of the DAB score was assessed by calculating the intraclass correlation coefficient (ICC) between DAB scores recorded by different researchers. The association between comfort and correctness of use was examined by observing children using booster seats (Part 2). The association between DAB score and number of usage errors was tested using linear regression analysis. Participants were children ages 4–8 years. Fourteen children participated in Part 1 and 15 children in Part 2.

Results: The DAB score was sensitive to changes in seat condition ($p < 0.01$), and was repeatable between different researchers (ICC 0.98, 95% confidence interval [CI] 0.954–0.991). Increases in DAB were associated with increases in the number of use errors among children using booster seats (errors in use $= 3.89 \times$ DAB $- 2.18$, $p < 0.0001$).

Conclusion: The DAB score is a reliable and valid measure of comfort of children in child restraints but could be improved by incorporating a measurement of postural positioning. Comfort, as characterized by fidgeting and postural adjustment behaviors, is associated with correct use of child restraints. The broader implication is that this confirms ergonomic design of child restraints as important for minimizing errors in use. There is a need for further study of the impact of specific restraint design features on comfort experienced by children.

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Introduction

In many jurisdictions across North America, Europe, Australia, and New Zealand, children must use age-appropriate restraint systems whenever they travel in a car. The use of age-appropriate restraints is known to significantly reduce the risk of death and injury to children in car crashes (Brown et al. 2006; Du et al. 2010; Durbin et al. 2005). However, the benefit of using an age-appropriate restraint is severely compromised if the restraint is used incorrectly. Children who incorrectly use restraints are at threefold risk of injury in a crash (Du et al. 2010). The population-level impact of increasing correct use depends on how many children are correctly restrained. With 50% of age-appropriate restrained children ages 1–6 years correctly using restraints, fatalities could be reduced by 14% and nonfatal injuries by 11% (Du et al. 2010). Similar benefits of correct use were reported by Elliot et al. (2006).

There are two main types of errors in the use of child restraints: installation errors and use errors. Installation errors occur when the restraint is being secured to the vehicle, and use errors occur when the child is secured into the restraint system and/or by the child's interactions with the restraint system during a journey. Several studies have suggested the latter may be related to discomfort (Charlton et al. 2006; Klinich et al. 1994; Osvalder et al. 2013; Simpson et al. 2002). Bohman et al. (2007) suggested that poor restraint fit could cause discomfort in children, and the avoidance of discomfort could result in severe misuse of restraints. However, there has been no attempt to

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Table 1. Experimental conditions, presented randomly.

Condition	State	*n*	Description
Fit	Comfortable baseline	14	Anthropometric fit based on buttock to popliteal length and sash belt crossing mid-clavicle
Fit + Footrest	Comfortable enhanced	14	Anthropometric fit based on buttock to popliteal length and sash belt crossing mid-clavicle with the introduction of a footrest to enhance comfort
Seatbelt High	Uncomfortable	14	Cushion length set to match buttock to popliteal length but with the seatbelt height adjusted to create sash belt contact with neck
Long Cushion	Uncomfortable	14	Cushion length set 10 cm too long for buttock to popliteal length, sash belt crossing mid clavicle

quantitatively examine the relationship between comfort and errors in the use of child restraints.

One barrier to the study of comfort and errors in use is the current lack of a validated, objective measure of comfort of children in cars. Among the few studies that have attempted to examine comfort of children in child restraint systems (Nilsson and Wolstedt 2007; Osvalder et al. 2013; Pettersson and Osvalder 2005), all have used some type of self-report tool to measure comfort levels. However, there has been no validation of this approach. Moreover, in other contexts, it is well known that there are inherent difficulties in surveying children due to the fact that cognitive, communicative, and social skills of children are still developing (Borgers et al. 2000; Borgers et al. 2004). To overcome this, observational methods are often used, for example, in measuring pain in children (von Baeyer et al. 2007). While there has been no attempt to measure comfort of children in cars through observation, other aspects of in-vehicle child behavior have been studied using video analysis (Forman et al. 2011; Klinich et al. 1994; Osvalder et al. 2013; Pettersson and Osvalder 2005). To date, these studies have concentrated on the posture and fit of the child in the seat. However, in one study, Osvalder et al. (2013) did note some postural shifts that they assumed to be related to discomfort. This included repositioning of the seatbelt, slouching, and general movements of the body and extremities. In another context, Harper et al. (2002) used video analysis to count fidgeting and stabilization movements such as postural adjustments to measure the level of comfort in a newly designed combination chair/step for children. This potential use of video analysis to assess comfort is interesting as it recognizes fidgeting behavior, as observed by Osvalder et al. (2013), as a sign of discomfort and attempts to quantify this behavior.

This study examines the reliability and sensitivity of a newly developed observational method inspired by the work of Harper et al. (2002) to assess comfort in children aged 4–8 years in different vehicle seating conditions, a method that uses a count of discomfort avoidance behaviors (DAB) to derive the DAB score as an objective measure of comfort. This novel method is then used to examine the relationship between comfort/discomfort measured in this way and errors in use of booster seats. The hypotheses tested were that (i) the DAB score would be sensitive to changes in seating conditions, (ii) the DAB score could be reliably obtained from different observers, and (iii) there is a significant relationship between comfort measured using the DAB score, and child-induced errors in booster seats.

Methods

This study consisted of two parts. In Part 1, the reliability and validity of using a video-based assessment to derive a Discomfort Avoidance Behavior (DAB) score in children in vehicle seats was examined. In Part 2, the association between the DAB score and observed errors in the use of child car booster seats was examined.

Participants

For both parts, parents/guardians and their children ages 4–8 years were recruited through advertisements posted on social media and public noticeboards. Recruitment for Part 1 took place between May 2013 and January 2014. Recruitment for Part 2 took place between January 2015 and October 2015. Informed consent for the child's participation was obtained from the parent. Parent participants were required to be over the age of 18 years, Australian residents, and routinely transporting the child. In Part 1, participants were reimbursed for their time with a gift voucher of AUD 25 value. Due to longer time requirements, participants in Part 2 studies were reimbursed to the value of AUD 50. Children wore their own clothes and shoes and were given no instructions on what to wear. A parent or guardian accompanied each child during all trials.

This study was approved by the University of New South Wales Human Research Committee (HREC Ref: HC13050 for Part 1, and HREA Ref: 08/2014/72 for Part 2).

Part 1: Reliability and sensitivity of the DAB score

Experimental design

A repeated-measures design with a seating buck designed to allow cushion length and seatbelt height adjustment was used to examine the sensitivity of a video based assessment of comfort in child occupants. Subjects experienced four different seating conditions, designed to induce different levels of comfort (see Table 1).

The seating buck was constructed from the rear seat of a popular small family sedan (2008 Honda Accord) mounted on a frame to allow the movement of the seat back relative to the seat cushion so that the cushion length could be shortened to match the buttock-to-popliteal length for each participant (from a maximum seat cushion length of 47 cm to a minimum length of 0 cm; the minimum actual cushion length used was 27 cm).

The frame also allowed the vertical position of the seatbelt D-ring to be altered from theoretical comfortable sash belt positions across the mid-clavicle to uncomfortable higher D-ring positions that allowed the sash belt to make contact with the child's neck. Possible D-ring heights ranged from 30 cm above the height of the seat back to 5 cm below the height of the seat back. The seat (Figure A1, see online supplement) was set up with a constant seat back angle (10 degree recline).

Seating conditions

The four seating conditions used in this trial are illustrated in Figure A1 (see online supplement). A comfortable "Fit" position was determined for each child based on the research by Parcells et al. (1999) using (i) a seat cushion length that corresponded to the buttock-to-popliteal length, and (ii) adjusting the seatbelt D-ring height so that the sash belt was placed in the optimal position midway across the shoulder, crossing the center of the chest without contacting the neck.

Three further seating positions were derived from the Fit position. The first was judged to be likely to be as comfortable as, or more comfortable than, the Fit position as it would relieve pressure on the children's thighs when the children's legs were too short to reach the floor. This Fit + Footrest position used the Fit position but added a footrest that was adjusted to allow the child to achieve a 90-degree bend at the knees. The third, designed to cause discomfort, was the Seatbelt High position, which took the Fit position but adjusted the seatbelt D-ring higher so that the sash belt was brushing the child's neck, as webbing rubbing the neck was expected to cause discomfort. The fourth, also designed to cause discomfort based on the work of Parcells et al. (1999), was the Long Cushion position, which was the Fit position with the cushion length adjusted to be 10 cm longer than the buttock-to-popliteal length, thereby preventing the child from bending his or her knee around the cushion edge.

(a) Seating buck constructed from rear seat of popular small family sedan

(b) Test buck based on a salvaged 2005 Volvo V50 with working rear driver's side door and interior trim and integrated booster seat (Booster 1)

(c) Add-on booster seat (Booster 2)

Figure 1. Seating modes used within Part 1 (a) and Part 2 (b, c) of this study.

Experimental procedure

Prior to the seating trials, stature, weight, and buttock-to-popliteal length were measured and a short demographics survey was completed by the parent.

For each condition, the child was correctly secured within the restraint and required to sit in the restraint for 10 min. No instructions on how to sit, or to use the foot rest were given to the child. The seating condition orders between participants were randomized. There was a minimum 10-min break after each trial, and parents were encouraged to take the child out of the room for a walk during these breaks.

During the trials, the child watched a children's TV program chosen prior to the commencement of the trial, throughout the 10-min trial interval. This video was displayed on a laptop with a 15-inch screen and in-built speakers, which was placed on a table directly in front of the seating rig just below eye level for the child, approximately an arm's length from the seated child.

For each trial, video was recorded simultaneously for later analysis.

Video assessment

Wide-angle video footage of the front left quarter view of the seating rig was recorded using a 720p digital camcorder secured to a tripod for each trial. Video footage was analysed using Kinovea (Version 0.8.15, Kinovea.org 2012) video analysis software. An analysis protocol was developed to calculate the rate of discomfort avoidance behaviors (DAB) observed. This potential novel method of quantifying comfort in child restraints was inspired by the work of Harper et al. (2002). Harper et al. (2002) counted fidgeting and stabilization movements to measure the level of comfort of children (ages 3–4 years) in high chairs. In the newly developed protocol for this current study, fidgeting and stabilization movements like those counted by Harper et al. (2002) have been interpreted to be discomfort avoidance behaviors (DABs), hence the genesis of the acronym DAB. In this current study these behaviors were defined as stretching of neck, stretching of back, shifting weight, leaning forward/backward or to either side, interacting with the sash belt, and kicking or moving of the legs. These behaviors were counted regardless of duration; this meant that combination behaviors were scored higher than a single behavior held for an extended duration.

Each video clip represented a single seating condition, and the total number of DAB instances was tallied for each clip and divided by the duration of the video clip (i.e., 10 min). This provided the average number of discomfort avoidance behaviors per minute, which we used as the DAB rate.

Reliability and sensitivity of the DAB score

The reliability of the DAB score was measured by having a second researcher repeat the scoring for nine participants and calculating the intraclass correlation coefficient (ICC) using a two-way mixed model for absolute agreement.

The sensitivity of the DAB score to changes in seating condition was assessed by comparing DAB scores in different seating conditions. We hypothesized that DAB scores would be significantly higher in anthropometrically uncomfortable positions. Paired-samples t-tests were used to individually compare the seating conditions to the baseline Fit. Bootstrapping was used to account for any nonnormal distribution of the data.

Part 2: The DAB score and errors in use of booster seats

Experimental design

A repeated-measures design was used to examine comfort and correctness of use among children using two different types of booster seats, an integrated booster (Booster 1) and an add-on high back booster (Booster 2) (Figure 1).

Table 2. Summary of anthropometric and demographic data of participants, using age at last birthday.

	Part 1					Part 2				
Subject	Gender	Height (cm)	Mass (kg)	Age (years)	BPL (cm)	Subject	Gender	Height (cm)	Mass (kg)	Age (years)
1	F	117	20	6	32	1	M	109.5	15	4
2	F	125	22	8	33.5	2	M	118	19	5
3	M	129	23	7	*	3	M	138	29	8
4	F	105	17	4	*	4	M	110	20	5
5	F	120	23	7	33	5	F	109	21	5
6	F	110	19	5	31.5	6	F	115	20	5
7	M	112	20	4	30	7	F	120	20	6
8	F	133	31	7	38	8	F	114	22	5
9	F	106	16	4	27	9	M	114	21	5
10	F	120	21	7	33	10	M	115	20	5
11	F	112	19	4	28	11	M	107	19	4
12	F	106	19	4	30	12	F	114	18	5
13	M	114	16	4	27	13	M	132	24	7
14	F	116	20	5	29	14	F	132	30	8
						15	F	137	31	7
	M	116.1	20.4	5.4			*M*	119.0	21.9	5.6
	SD	8.6	3.8	1.5			*SD*	10.5	4.6	1.3

Seating conditions

As the integrated restraint required the use of a vehicle seat incorporating this form of booster, all trials in Part 2 were conducted on a seating buck constructed from a salvaged 2005 Volvo V50 station wagon that had been cut to remove the front cabin from the B-pillar forward and the cargo area rear of the C-pillar. This retained the rear passenger cabin and the driver's seat with a functioning driver's side rear door (Figure 1). The remaining hulk was then placed on a wheeled, wood and steel platform that allowed movement. The rear passenger compartment retained all the interior trim, including the leather seats and the rear driver side door. The buck incorporated a single-stage integrated booster seat. The additional high-backed, add-on booster (Figure 1) meets the current Australian Standard (AS/NZS1754 2013) and was selected as it is one of the boosters with highest ease of use rating from the Australian child restraint consumer information program (CREP). Both types of booster are similar to those available in other countries.

Experimental procedure

The parent was asked to secure the child into each restraint and make any adjustments the parent deemed necessary. Any errors introduced by the parent were noted and corrected before the commencement of the video protocol. No instructions were given to the child. The child was then recorded while secured in the restraint for 10 min as per the DAB protocol. Participants had access to both the vehicle user's manual and the add-on restraint's instruction manual. All participants used the add-on booster first, and the integrated booster second.

Video assessment

The same video protocol as in Part 1 was used to derive the DAB score for each child in each restraint. Reliability of the scoring protocol was confirmed by having a second researcher repeat the scoring for five participants on each restraint and calculating the intraclass correlation coefficient (ICC) using a two-way mixed model for absolute agreement.

The video was also used to identify any errors in use introduced by the child. An error in use was defined as any active mispositioning of the seatbelt or extreme postural shifts such as leaning forward or sideways beyond the natural confines of the restraint system.

Analysis

General estimating equations were used to conduct a generalized linear regression analysis of the association between DAB score and errors introduced by the child while accounting for the repeated measures design. Parent errors were not included in this analysis. This method allows for the analysis of nonparametric data sets and is robust to the effects of heteroscedasticity. Statistical analysis was performed using SPSS (IBM SPSS Statistics for Windows, Version 22.0, IBM Corp., Armonk, NY).

Results

Table 2 presents characteristics of the participants in Part 1 and Part 2 of this study.

Reliability and sensitivity of the DAB score

The average intra class correlation coefficient (ICC) between researchers across the four seating conditions was 0.98 (95% confidence interval [CI] 0.954–0.991, $F(31, 31) = 61.425$, $p < 0.001$), indicating a high degree of agreement.

Table 3 reports the DAB score for each participant in each seating condition, and mean (M) and standard deviation (SD) of DAB scores in each seating condition from Part 1. Paired-sample t-tests revealed the DAB score significantly increased by more than 40% between the Fit condition and the Seatbelt High condition ($p < 0.01$, $n = 13$). No other significant differences were observed between any conditions (Figure 2).

Association between DAB and errors in use

DAB scores in Part 2 ranged from 0.29 to 2.5 (M = 1.33, SD 0.608). Intraclass correlation coefficients using two-way mixed model testing for absolute agreement showed excellent agreement for DAB scores calculated from observations of children

Table 3. DAB scores for different seating conditions.

Subject	Fit	Fit + Footrest	Seatbelt High	Cushion Long
1	0.98	—	1.92	0.89
2	0.3	1.29	0.73	0.66
3	1.06	0.93	1.51	1.37
4	0.11	0.58*	1.08	0.88
5	0.79	1.17	1.66	0.65
6	2.42	2.16*	1.9	1.39
7	0.87	0.61	1.26	0.71
8	0.67	0.85	1.78	1.47
9	1.95	2.3*	3	1.85
10	2.89	2.29*	2.82	2.8
11	0.97	0.78	1.4	1.39
12	1.76	1.31*	1.69	2.29
13	1.3	2.32	2.89	1.97
14	1.18	1.25	1.61	0.85

* Footrest used only intermittently.

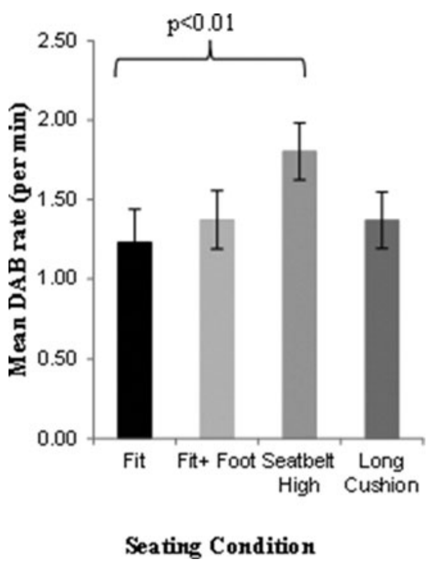

Figure 2. Comparison of DAB scores between the anthropometric Fit condition and other tested seating conditions, $n = 14$.

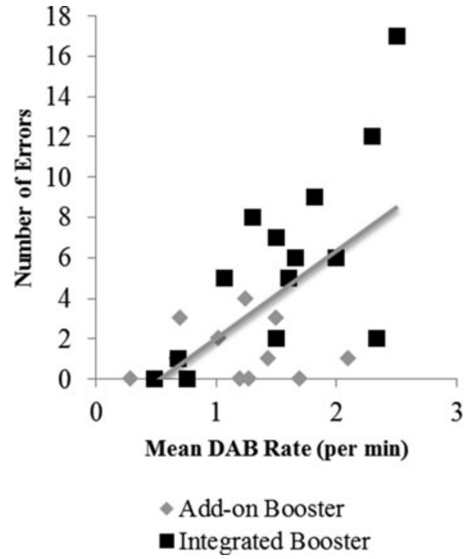

Figure 3. Relationship between the number of errors in restraint use and the mean DAB rate showing the mean DAB rate increases with the number of restraint errors, $n = 28$.

using both the integrated restraint (ICC = 0.954) and the add-on booster (ICC = 0.997).

A small number of parent-introduced errors ranging from 0 to 3 per parent (M = 0.73, SD 1.16) were observed with the add-on booster, but no parent-introduced errors were observed with the integrated booster. Child-introduced errors were observed with both boosters. There were significantly more use errors with the integrated booster seat (range = 0–17 errors/child, M = 5.40, SD = 4.79) than with the add-on booster (range = 0–3 errors/child, M = 1.20, SD = 1.32), ($t(14) = 4.2$, $p < 0.01$).

Parent errors involved failure to use belts guides, and failure to remove twists from the seatbelt. The types of child-induced errors observed included the child moving the seatbelt off the shoulder, positioning the belt under the arm, holding the seatbelt away from the neck, holding seatbelt away from body, completely removing the seatbelt, removing the belt from belt guides, unbuckling the seatbelt, the child sliding under the lap portion of the seatbelt, the child leaning forward, and the child leaning sideways. Full details of the child-induced errors observed in each booster are provided in Supplementary Table 1 (see online supplement).

A scatterplot summarizes the results (Figure 3). The generalized linear regression analysis shows that increases in DAB were correlated with increases in the number of child-induced errors (errors in use = 3.89 × DAB – 2.18, $p < 0.0001$). This relationship remained significant when controlling for restraint type (errors in use = 3.00 × DAB – 2.94 + 0.45, $p = 0.001$).Adding height and or age to the model had no effect on this significant relationship. However, the full model also revealed a significant relationship between restraint type and errors in use ($p = 0.002$), and between height of child and errors in use ($p = 0.045$).

Discussion

The main findings of this study are that the video-based observational method using a count of fidgeting and stabilization movements (DAB score) was sensitive to discomfort induced by changes in shoulder belt position, and increase in this measure of discomfort was associated with errors in the use of booster seats. Very high interrater reliability of the method suggests it is repeatable. These results demonstrate that the comfort experienced by a child is important to correct use of child restraints.

In examining the sensitivity of the DAB score we assumed comfort is maximized by a good ergonomic match between child and seat, based on research by Parcells et al. (1999) that linked seating ergonomics with comfort and posture. Of particular interest are the measures of buttock–popliteal length and popliteal height as compared to the seating surface. From their review, "If the seating surface is too high, the underside of the thigh becomes compressed causing discomfort" (Parcells et al. 1999), indicating a relationship between these measures and discomfort. We also hypothesized that positioning the seatbelt across the neck would induce discomfort. We therefore expected that discomfort would be induced in both the Seatbelt High seating condition (which resulted in a higher DAB rate) and the Long Cushion conditions (which did not result in a higher DAB rate).

We observed that all participants quickly shuffled forward in the Long Cushion condition to find a comfortable position that allowed their knees to bend around the seat edge, a response to discomfort that may increase comfort but induced poor restraint fit. This demonstrates a limitation of the current DAB score method since a single behavior does not produce a high score, regardless of how long that behavior is maintained. The DAB method may be improved by adding a measurement of postural shift similar to that performed by Forman et al. (2011), and/or a measure of time out of position.

As shown in Table 3, not all children used the footrest for the entire length of the Fit + Footrest trial. This might explain why there was no significant reduction in the DAB score for this condition compared to the Fit condition, since in theory children who could bend their knees around the cushion edge and rest their feet were thought to be in a more comfortable position. However, in this study children were not given any instructions on using the foot rest. The fact that some children chose not to use the footrest may also indicate that it did not improve their comfort. This could be studied in the future by examining changes in the DAB score when children are instructed when to use and not use the foot rest.

The Part 1 trials were designed to examine the sensitivity of the DAB score to theoretical changes in comfort. While other aspects of the seat, such as the shape and feel of the seating surface and lap belt geometry, may also influence comfort, these characteristics were held constant across the seating conditions. The influence of these across the four seating conditions was therefore the same, but it remains unknown how these might influence the overall comfort experienced by a child. Similarly, the influence of raising the seated height with respect to the lap belt geometry as would occur with a booster seat and the influence of the constant seat back angle as the cushion length changes remain unknown.

In the booster seat trials, we did not assess the anthropometric match between the children and the seating surfaces of the booster seats or the seatbelt, as these restraints are specifically designed to accommodate children of the size range of our participants.

Given the high DAB rate observed, it would appear the booster seats used in the Part 2 trials may not have been successful in improving the match between the child and the vehicle's seatbelt geometry for all children who participated in this study. Previous work has demonstrated that not all booster seats are successful in meeting their objective of optimizing seatbelt fit in test dummies (Brown et al. 2009; Reed et al. 2009). In Australia, the ability of a booster seat to provide good seatbelt positioning is now regulated through the Australian Standard and assessed in the Australian Child Restraint Evaluation Program. Static fit is also assessed in the insurance Institute for Highway Safety's Booster ratings. Many high-back booster seats use sash guides to assist in improving sash belt position; however, in laboratory studies, McDougall et al. (2011) demonstrated the difficulty booster seats have in achieving this with variations in seatbelt geometry in all vehicles. The results of this current study suggest this is a problem not only for optimized crash protection, but possibly also for misuse. Misuse further degrades the protective effect of the seatbelt.

The broader implication of the association between comfort and errors in use observed in this study indicates that ergonomic design of child restraints may help to minimize errors in use. There is a need for further study of the impact of specific design features on child comfort.

In this study overall higher DAB scores and more errors were observed with Booster 1 (the integrated booster seat) than with Booster 2 (the add-on high-back booster). However, caution is recommended in making any assumptions from this result, as the order in which children were observed in the different boosters in the Part 2 experiments was not randomized. Each participant was seated in Booster 2 and then in Booster 1 with a break of at least 10 min. It is possible the increase in discomfort and/or errors observed in Booster 1 reflects some aspects of the child's boredom with the trials, rather than differences in booster design. Furthermore, because of this lack of randomization, this observation cannot be used to suggest misuse is more likely in one booster type compared to another. However, observation studies of children using restraints in the real world have reported variations in rates of errors in different restraint types, for example, more errors in convertible restraints compared to restraints designed for single mode use (Brown et al. 2010). It is possible that specific design features may impact misuse through the impact they have on child comfort. Moreover, the extreme and consistent differences in the behavior of the children in the two restraints suggests that regardless of the ordering effect, differences in the design of these two seats may be influencing these behaviors. This requires further examination in a study designed and powered to examine the influence of specific aspects of restraint design on child behavior.

It is important to note that some more extreme behaviors such as moving the torso forward or sideways sufficiently that the child's body is beyond the confines of the restraint system that are counted for the DAB score also represent errors in use, and this overlap may have artificially have strengthened the association between DAB score and incorrect use. In the Part 2 study, behaviors associated with fidgeting with the seatbelt, as well as gross torso movements and so on, occurred less in the anthropometrically predicted comfortable positions. However, to increase confidence in the association between comfort as measured by the DAB score and errors in use, further work examining errors in use in other types of restraints not relying on the adult seatbelt, that is, rearward and forward facing child seats, is planned.

Besides those already mentioned, there are some other limitations to keep in mind. This work was conducted in a laboratory environment and it is possible the environment may also have impacted on the behavior of the child. Both Part 1 and Part 2 studies observed children in each seating condition for a period of 10 min and behavior may be different over longer and shorter time intervals, and in a vehicle on the road. To overcome these limitations, the work reported here will be repeated in a naturalistic driving study.

This work did not attempt to take account of inherent variations in the behavior of individual children. While this would not have impacted the comparative results presented here, this should be taken into account in studies examining differences in comfort/behavior in children using different restraint systems, or restraint systems with different design features. It is also important to remember that the relationship being studied is that between comfort and errors in use, as introduced by the child. Further work is required to examine any relationship between parent-perceived comfort and errors introduced by the parent when securing the child within the restraint. Finally, the reliability of the DAB scoring protocol was examined using two researchers; further examination of the protocol could be improved by confirming reliability using a greater number of raters.

While the results of this study indicate that comfort experienced by a child can be objectively and quantitatively studied using the DAB protocol, and there appears to be an association between comfort and errors confirming previous unsubstantiated suggestions in the literature (Charlton et al. 2006; Bohman et al. 2007; Klinich et al. 1994; Osvalder et al. 2013; Simpson et al. 2002), the limitations of this study mean that caution should be applied in further interpretation of the results. In particular, the finding that the DAB score was not sensitive to the Long Cushion and Fit plus Footrest condition indicates there is significant scope to improve the DAB score as a measure of comfort. Furthermore, the fact this current study was not designed to investigate differences in comfort, or misuse by booster seat type, means that the observations about differences in behavior between the two types of booster should be viewed with caution. It is also unclear whether these findings will apply to real-world restraint use, and this needs further study, perhaps using naturalistic methods.

The strength of this current work is that it is the first to attempt to examine the relationship between comfort and errors in use using a validated method of measuring comfort. In addition to the insights this work provides about potential mechanisms underpinning the widespread and long-standing problem of child restraint misuse, this work also introduces a potentially useful method for use in naturalistic studies examining occupant behavior.

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References

AS/NZS1754. Child restraint systems for use in motor vehicles. AS/NZS 1754:2013. 2013. Available at: https://www.saiglobal.com.

Bohman K, Boström O, Osvalder AL, Eriksson M. Rear seat frontal impact protection for children seated on booster cushions-an attitude, handling and safety approach. In: Proceedings of the 20th International Technical Conference of the Enhanced Safety of Vehicles, Paris, France, June 2007.

Borgers N, de Leeuw E, Hox J. Children as respondents in survey research: Cognitive development and response quality 1. *Bull. Methodol Sociol.* 2000;66(1):60–75.

Borgers N, Sikkel D, Hox J. Response effects in surveys on children and adolescents: The effect of number of response options, negative wording, and neutral mid-point. *Qual Quantity.* 2004;38(1): 17–33.

Brown J, Hatfield J, Du W, Finch CF, Bilston LE. The characteristics of incorrect restraint use among children traveling in cars in New South Wales, Australia. *Traffic Inj Prev.* 2010;11(4):391–398.

Brown J, Kelly P, Suratno B, Paine M, Griffiths M. The need for enhanced protocols for assessing the dynamic performance of booster seats in frontal impacts. *Traffic Injury Prev.* 2009;10(1):58–69.

Brown J, McCaskill ME, Henderson M, Bilston LE. Serious injury is associated with suboptimal restraint use in child motor vehicle occupants. *J Paediatr Child Health.* 2006;42(6):345–349.

Charlton JL, Wales NS, Authority MA. *Factors That Influence Children's Booster Seat Use*. Clayton, Victoria, Australia: Monash University Accident Research Centre; 2006.

Du W, Finch CF, Hayen A, Bilston L, Brown J, Hatfield J. Relative benefits of population-level interventions targeting restraint-use in child car passengers. *Pediatrics.* 2010;125(2):304–312.

Durbin DR, Chen I, Smith R, Elliott MR, Winston FK. Effects of seating position and appropriate restraint use on the risk of injury to children in motor vehicle crashes. *Pediatrics.* 2005;115(3):e305–e309.

Elliott MR, Kallan MJ, Durbin DR, Winston FK. Effectiveness of child safety seats vs seat belts in reducing risk for death in children in passenger vehicle crashes. *Arch Pediatr Adolesc Med.* 2006;160(6): 617–621.

Forman JL, Segui-Gomez M, Ash JH, Lopez-Valdes FJ. Child posture and shoulder belt fit during extended night-time traveling: an in-transit observational study. *Ann Adv Automot Med.* 2011;55:3–14.

Harper K, Mallin D, Marcus N, McElheny M, Miller T, Navai M, Ruder M, Tolin E, Wolkoff J, Zuniga A, et al. *Ergonomic Evaluation of the KinderZeat Child Seat in a Preschool Setting*. Class Project Report. 2002:1–18. Available at: http://ergo.human.cornell.edu/ErgoPROJECTS/DEA4702002/KZProject/KZ%20StudyReportMay02.pdf.

Klinich KD, Pritz HB, Beebe MS, Welty KE. Survey of older children in automotive restraints. In: SAE Publication P-279. Proceedings of the 38th STAPP Car Crash Conference, Fort Lauderdale, Florida, USA, October 31–November 4, 1994 (SAE Technical Paper 942222): 245–258.

McDougall A, Brown J, Beck B, Bilston LE. The effect of varied seat belt anchorage locations on booster seat sash guide effectiveness. In: 22nd International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, D.C., June 13–16, 2011:11–0135.

Nilsson E, Wolstedt V. 2007. Concept and development of an ergonomic booster seat. In: Proceedings of the Nordic Ergonomic Society (NES) Conference, Lysekil, Sweden, October 1–3, 2007.

Osvalder A-L, Hansson I, Stockman I, Carlsson A, Bohman K, Jakobsson L. Older children's sitting postures, behavior and comfort experience during ride—A comparison between an integrated booster cushion and a high-back booster. In: International Research Conference on the Biomechanics of Impact (IRCOBI) Gothenberg, Sweden, 2013.

Parcells C, Stommel M, Hubbard RP. Mismatch of classroom furniture and student body dimensions: Empirical findings and health implications. *J Adolesc Health.* 1999;24(4):265–273.

Pettersson I, Osvalder AL. Ergonomic evaluation of child car seats comfort and usability. In: Proceedings of the Nordic Ergonomic Society (NES) Conference, Oslo, Norway, October 9–11, 2005.

Reed MP, Ebert SM, Sherwood CP, Klinich KD, Manary MA. Evaluation of the static belt fit provided by belt-positioning booster seats. *Accid Anal Prev.* 2009;41(3):598–607.

Simpson EM, Moll EK, Kassam-Adams N, Miller GJ, Winston FK. Barriers to booster seat use and strategies to increase their use. *Pediatrics.* 2002;110(4):729–736.

Von Baeyer CL, Spagrud LJ, others. Systematic review of observational (behavioral) measures of pain for children and adolescents aged 3 to 18 years. *Pain.* 2007;127(1–2):140–150.