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Variations in booster seat use by child characteristics

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ABSTRACT

INTRODUCTION: Child weight and height are the basis of manufacturer and best practice guidelines for child restraint system use. However, these guides do not address behavioral differences among children of similar age, weight, and height, which may result in child-induced restraint use errors. The objective of this study was to characterize child behaviors across age in relation to appropriate restraint system use during simulated drives.

METHODS: Fifty mother-child (4-8 years) dyads completed an installation into a driving simulator, followed by a simulated drive that was video-recorded and coded for child-induced errors. Time inappropriately restrained was measured as the total amount of the simulated drive spent in an improper or unsafe position for the restraint to be effective divided by the total drive time. Kruskal-Wallis tests were used to determine differences across age in the frequency of error events and overall time inappropriately restrained.

RESULTS: Children in harnessed seats had no observed errors during trips. Within children sitting in booster seats there were differences in time inappropriately restrained across age (p=0.01), with 4 year-olds spending on average 67% (Median= 76%) of the drive inappropriately restrained, compared to the rest of the age categories spending less than 28% (Medians ranged from 3-23%).

CONCLUSION: Some children may be physically compatible with booster seats, but not behaviorally mature enough to safely use them. More research is needed that examines how child behavior influences child passenger safety.

PRACTICAL APPLICATIONS: Not all children physically big enough are behaviorally ready to use belt positioning booster seats. Primary sources of information should provide caregivers with individualized guidance about when it is appropriate to transition children out of harnessed seats. Additionally, best practice guidelines should be updated to reflect what behaviors are needed from children to safely use specific types of child restraint systems.

KEY WORDS: child passenger safety; child restraint systems; injury prevention; child occupant protection; human factors

INTRODUCTION

Recent updates to the American Academy of Pediatrics (AAP) best practice guidelines regarding child restraint systems (CRS) direct caregivers to focus on their child's weight and height and the limits listed by seat manufacturers.[1] While this is a good starting point, a lack of specificity in the guidelines combined with a wide array of manufacturer specifications across seats (i.e., different weight/height requirements for different brands and models of the same type of seat) may provoke caregivers to seek more individualized guidance or information from trusted sources of information (e.g., Primary Care Physicians, Child Passenger Safety Technicians or CPSTs). However, providing this individualized information and guidance may be more nuanced than it at first appears, especially when considering when it is time to transition a child from a harnessed seat to a belt positioning booster seat.

For example, while the best practice guidelines do indicate that delaying transitions between each seat is best, and that several forward-facing harnessed seats can now accommodate children up to 65 lbs, many high-back booster seats have minimum weight requirements of 30 lbs. Current percentiles for weight in the United States list that 30 lbs (~13.6 kg) is the 50th percentile of weight for boys aged 2.6 years and for girls aged 2.9 years.[2] Therefore, according to some manufacturer guidelines, 50% of children may be physically heavy enough to ride in a belt-positioning booster seat *before* they are 3 years old. Indeed, a 2016 study in Australia found nearly 40% of 2 year-old children were inappropriately restrained- approximately 20% of these 2 year-olds were prematurely sitting in booster seats.[3] Compared to booster seats, harnessed seats may reduce the risk of fatality for children 2-5 years old involved in MVCs by 50%.[4]

Booster seats may be appealing to some caregivers because they are easier to install in vehicles, more conducive to families with multiple children (i.e., take up less space in a vehicle, easier to put child in), and are typically much less expensive than harnessed restraints. However, compared to harnessed seats, booster seats can allow children more mobility and flexibility to sit in a range of postures, which could interfere with the seat's ability to protect the child in the event of a motor vehicle crash (MVC).[5–8] Importantly, when determining manufacturer guidelines and effectiveness, seats are tested in *optimal* use conditions, yet children may not travel under these conditions in daily life.

Current Study

By focusing on a child's weight and height, caregivers may be at risk for prematurely transitioning their children to CRS in which they are physically compatible, but not behaviorally ready to use. This mixed-methods study was designed to characterize child behaviors across age in relation to appropriate CRS use during a driving simulation. Mothers of children 4-8 years old installed a CRS into the backseat of a driving simulator and restrained their child into the seat. Dyads were then video-recorded during a simulated trip. Videos were coded for child-induced posture, belt, and "other" errors (described below). We hypothesized that younger children would have more child-induced errors and spend more time in unsafe positions than older children.

METHODS

Study Overview

A convenience sample of mothers completed a self-report phone survey, and within four weeks the mother-child dyads attended an in-person study visit for two observational assessments. Mothers were remunerated with $40 and children received a prize from a prize box (prizes were worth approximately $1 in value). Mothers also received an age-appropriate CRS for their child, personalized feedback about their CRS use from a certified CPST, and were directed to community resources as appropriate. The study protocol was approved by the Institutional Review Board of the University of Alabama at Birmingham.

Participants

Participants were recruited between June 2018 and January 2019 from the greater Birmingham, Alabama area using electronic flyers on social media, paper flyers posted around the community, and radio advertisements. Eligible participants could travel to the study site for the observational assessments, were biological mothers of a child between 4-8 years old, and fluent in written and spoken English.

Eighty-nine potential participants contacted the study team. Of these, 2 (2%) were ineligible because they were not the biological mothers of the child, 3 (3%) were ineligible because of their children's ages, and 2 (2%) were eligible but did not enroll because of time concerns. The final eligible sample consisted of 82 mother-child dyads. After enrollment, 20 (24%) of these did not attend the in-person observations. Participants who enrolled but did not attend the observations did not differ from those who attended the observations on race (p=0.26) or education (p=0.24), however they were more likely to be single (p=0.03). The final analytic sample was 50 mother-child dyads; 12 dyads were unable to complete the simulated drive.

Surveys

Prior to the in-person observational visit, mothers completed a brief phone survey and self-reported caregiver and child age, sex, race/ethnicity, and previous diagnoses of or treatment for Attention Deficit Hyperactivity Disorder (ADHD)/Attention Deficit Disorder (ADD), Autism Spectrum Disorder (ASD), and Obsessive Compulsive Disorder (OCD). Mothers also answered questions about their highest completed level of education and marital status.

Observational Assessments

Upon arrival to the study visit, a CPST assessed the mother's vehicle for real-world use of CRS, and then collected the child's weight (kg) and height (in). The child was given a brief tour of the simulator and asked if they would like to take a short drive inside it with their mother. The mothers were given a commercially available CRS, the CRS manual, and verbal instructions to install the seat into the driving simulator using whatever method was most comfortable (both LATCH and seat belts were available). CRS options were a forward facing 5-point harness or a high-back booster seat. The type of seat that the mother installed was determined by the seat the participants used in their personal vehicle (e.g., if a 5-point harness was being used in the personal vehicle, then the mother installed a 5-point harness into the simulator). All children that were observed to be using a CRS in their family's personal vehicle were within weight/height limits of their seat. If no seat was used in the personal vehicle, the child's weight and height were used to determine if they were large enough to use a booster seat. Of the 50 who completed the simulated drive, 14 participants were in a harnessed seat and 20 were in a booster seat. Sixteen who were in nothing met the height/weight requirements of the belt positioning booster seat, and therefore used the booster seat for the installation. After the installation, dyads took a short drive in the simulator to give the child time to behave as they typically would during a drive, which was recorded by a mounted camera on the windshield.

Driving Simulator and Trip Description

The driving simulator is a high-fidelity, fully immersive instrument designed by Realtime Technologies, Inc. outfitted with a 2016 Honda Pilot featuring a fully functional steering wheel, throttle, brake, gear selector, turn signals, and dashboard, and is placed on a motion base system. For this project, the motion base was turned off to accommodate for odd weight distribution during seat installation. The simulator also included a bench back seat, with working seat belts and LATCH systems.

The simulated drive began in a rural, residential environment and traveled into an urban environment. Other simulated vehicles were present throughout the drive, as were buildings, animals, trees, and common street signs/road markings. The drive did not require the participant to change lanes or make any turns. The drive also included one red-light, which transitioned from red to green after each participant had been stopped for one full minute. The trip was designed to last 10 minutes or less. Variable times during the drive were a result of different speeds driven by the participants. Research assistants remained in an adjacent control room during the entire trip. Children did not have anything to distract or entertain them during the drive (e.g., games, mobile devices, books).

Video Data

Video data recorded was coded by two independent raters using the software Mangold INTERACT[9] to assess child-induced errors or safety violations. One of the video coders was a CPST, and therefore was used as the “gold standard”. There were 3 categories of codes: (1) posture errors (*child leaning forward so that back is not touching seat*, *lateral movement so that the child’s torso is not within the seat edges, turning around to look out of the rear window*), (2) restraint errors (*child moving belt behind their back*, *child moving belt under his/her arms,* or *child moving restraint in a different not-approved position*), or (3) “other” errors, which were created after beginning the coding process (*child lifting body out of seat*, *child slouching down in seat*).

A video of a dyad that completed most of but not the entire drive was used as a practice coding video until interrater reliability was $\geq$ 0.7 (Cohen’s kappa; actual reliability for the practice video was 1.0). Because of the small sample size and the short length of the videos, each video was required to have an interrater reliability of at least 0.7. Three videos were coded three times independently without agreement. These videos were watched together with both coders to decide on appropriate codes and to discuss differences in ratings.

Statistical Approach

After video coding was complete, trip characteristics were recorded to determine the proportion of time each child spent in an "unsafe" position or restraint. First, coders determined the number of times each child committed a specific type of error and the overall time (in seconds) that a child was in that error category for the whole drive (e.g., if a child turned around to look out of the rear window 3 times for 1 second each time, the child would have 3 rear window events for a total time of 3 seconds). These scores were used to create the percentage of "time improperly restrained" (TIR) variable, which was the total amount of the drive spent in an unsafe position divided by the total drive time. Kruskal-Wallis tests compared age categories across types of errors coded. All statistical analyses were conducted in SPSS v. 24[10] and R version 3.4.1[11].

RESULTS

Participants

Participant demographics are shown in Table 1. For the simulated drives, 7 participants ended the drive early because of simulator sickness, 1 participant had an extra child sitting in the vehicle, 1 child weighed too much to sit in a booster seat, 1 participant ended the study visit early, and 2 drives were not recorded by the camera because of technical error. This left an analytical sample of 50 participants.

Table 1. Participant characteristics by seat used in driving simulation (n=50)

Variable	Children in 5-point Harness: N (%)	Children in Booster Seats: N (%)	Total N (%)
Child Age in Years (Mean =5.44)			
4	8 (57)	8 (22)	16 (32)
5	5 (36)	8 (22)	12 (24)
6	1 (7)	7 (19)	9 (18)
7	0	10 (28)	10 (20)
8	0	3 (8)	3 (6)
Child Sex			
Boy	6 (43)	16 (44)	22 (44)
Girl	8 (57)	20 (56)	28 (56)
Race			
White	10 (71)	11 (31)	21 (42)
Black/African American	3 (21)	24 (67)	27 (54)
Mixed-Race	1 (7)	1 (3)	2 (4)
Mother's Education			
Some High School	0	3 (8)	3 (6)
High School/GED	4 (29)	5 (14)	9 (18)
Some College	3 (21)	8 (22)	11 (22)
Associate's Degree	0	8 (22)	8 (16)
Four-year Degree	3 (21)	5 (14)	9 (18)
Master's Degree	3 (21)	5 (14)	7 (14)
Professional Degree	0	2 (6)	2 (4)
Doctoral Degree	1 (7)	0	1 (2)
Marital Status			
Married	11 (79)	19 (53)	30 (60)
Single/Never Married	3 (21)	13 (36)	16 (32)
Living with Partner	0	2 (6)	2 (4)
Separated	0	2 (6)	2(4)
Diagnoses-Mother			
ADHD/ADD	1 (7)	1 (3)	2 (4)
ASD	0	0	0
OCD	0	3 (8)	3 (6)
Diagnoses-Child			
ADHD/ADD	0	6 (17)	6 (12)
ASD	0	0	0
OCD	0	0	0
Using CRS in Personal Vehicle			
Yes	14 (100)	20 (56)	34 (68)
No	0	16 (44)	16 (32)
Seat Used in Drive			
Harness	-	-	14 (28)
Booster			36 (72)

Table 1 note: Percentages rounded to nearest whole number.

Mothers' and children's ages ranged from 23 to 42 years old (Mean=33, SD= 5.28) and from 4-8 years old (Mean=5, SD=1.29). The majority of mothers were married (n=30), had obtained an Associate’s degree or less (n=31), and were Black/African American (n=27). The majority of children were girls (n=28); children’s weights ranged from 14.7- 44.6 kg, and their heights ranged from 38.4 in- 54.4 in. There were 6 children and 1 mother who had previous diagnoses of ADHD/ADD. The majority of installations were completed using a high back booster seat (n=36).

Video Coding

All 50 videos reached the minimum interrater reliability (range of kappa= 0.7-1.0). Harnessed children were not observed to have any child-induced errors during the simulated drive. Because of this, the following descriptive information and statistical analyses of observed errors are limited to the 36 children in booster seats. Drives lasted between 374-598 seconds (Mean= 471.42, SD=53.92; the distribution of errors per category, the time each child spent in an error, child sex, and child age are in Supplementary Table 1).

Time Inappropriately Restrained

The total number of child-induced error events and TIR for each category of error by child age are presented in Table 2, and the frequency of specific error events and the amount of time spent in them by child age are presented in Table 3. The total number of error events for each child ranged from 0-36 (Median= 8, SD=9.33), and the sum of the time spent in error ranged from 0-464 seconds (Median=96, SD=151.50). Four year-olds (n=8) on average spent 67% of the total drive inappropriately restrained (Median= 76%) (Figure 1); the median number of errors observed in this age group was 17.5. In comparison, average TIR for 5 year-olds (n=8) was 16% (Median= 3%), 6 year-olds (n=7) was 28% (Median=21%), 7 year-olds (n=10) was 23% (Median=23%), and 8 year-olds (n=3) was 21% (Median=4%), and the median number of errors observed in each of these age groups was 2, 9, 8, and 5, respectively. A Kruskal-Wallis test yielded differences in the median TIR across age analysis (p=0.01), but not in error event frequencies (p=0.08).

Figure 1. Child age and proportion of total drive spent in unsafe position

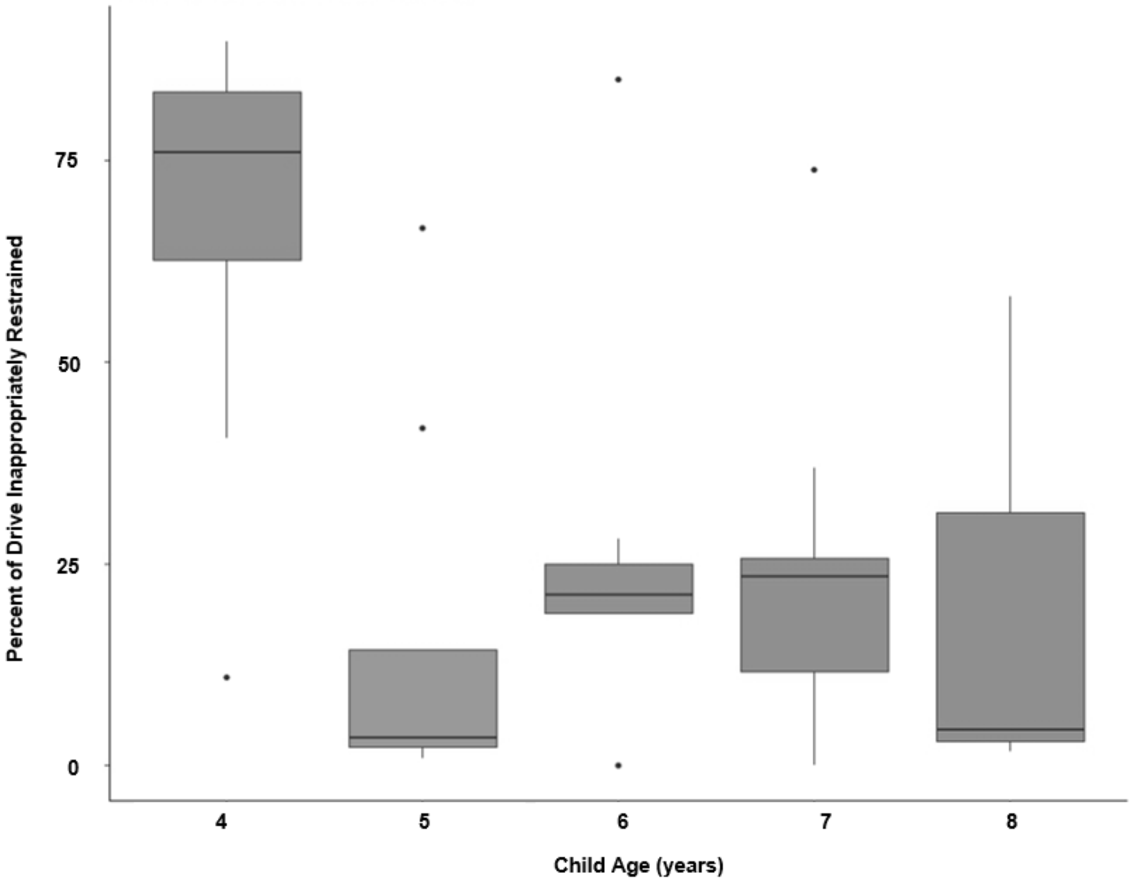

Figure 1. Black dots represent outliers for each age group, lines indicate median time inappropriately restrained. Group sizes were: 8 four-year olds, 8 five year-olds, 7 six year-olds, 10 seven year-olds, and 3 eight year-olds.

Table 2. Total number of error events and percentage of Time Inappropriately Restrained

	Number of Events **Median (Range)**	**Total TIR (%)** **Median (Range)**
All Children	4 (0-36)	22 (0-90)
4 year-olds	17.5 (5-36)	76 (11-90)
5 year-olds	2 (1-13)	3 (1-42)
6 year-olds	9 (0-35)	21 (0-85)
7 year-olds	8 (0-24)	23 (0-74)
8 year-olds	5 (1-12)	4 (2-58)

Table 2 note. Kruskal-Wallis comparisons across ages resulted in p=0.08 for number of events and p=0.01 for TIR. Percentages rounded to nearest whole number.

Table 3. Total number of each error event and total time of error event by child age (years)

Error Category		Number of Events Median (Range)	p	Time in Error (s) Median (Range)	p
Posture Specific Errors (total)					
	All children	8 (0-34)	0.10	90 (0-366)	0.20
	4 year-olds	17 (5-26)		162 (44-359)	
	5 year-olds	2 (1-13)		13 (3-268)	
	6 year-olds	9 (0-34)		92 (0-366)	
	7 year-olds	8 (0-24)		81.5 (0-317)	
	8 year-olds	5 (1-10)		24 (7-196)	
Leaning forward					
	All children	4 (0-18)	0.03	76.5 (0-348)	0.22
	4 year-olds	11 (1-18)		137 (6-348)	
	5 year-olds	1 (0-8)		5 (0-249)	
	6 year-olds	6 (0-17)		77 (0-336)	
	7 year-olds	4 (0-12)		66 (0-311)	
	8 year-olds	2 (0-6)		76.5 (0-181)	
Lateral movement					
	All children	1 (0-7)	0.13	1 (0-23)	0.12
	4 year-olds	1 (0-3)		7 (0-13)	
	5 year-olds	0 (0-2)		0 (0-9)	
	6 year-olds	0 (0-7)		5 (0-23)	
	7 year-olds	0 (0-5)		0 (0-21)	
	8 year-olds	0 (0-1)		0 (0-3)	
Turning to rear window					
	All children	2 (0-15)	0.64	7 (0-51)	0.42
	4 year-olds	4 (0-5)		15.5 (0-30)	
	5 year-olds	0.5 (0-7)		1.5 (0-19)	
	6 year-olds	1 (0-15)		5 (0-51)	
	7 year-olds	4.5 (0-13)		12 (0-36)	
	8 year-olds	2 (1-4)		9 (7-15)	
Belt Specific Errors (total)					
	All children	0 (0-3)	0.02	0 (0-369)	<0.01
	4 year-olds	1 (0-3)		167 (0-369)	
	5 year-olds	0 (0-2)		0 (0-13)	
	6 year-olds	0 (0-1)		0 (0-9)	
	7 year-olds	0 (0-1)		0 (0-57)	
	8 year-olds	0 (0-2)		0 (0-53)	

Error Category	Number of Events Median (Range)	p	Time in Error (s) Median (Range)	p
Moving belt under arm				
All children	0 (0-3)	0.08	0 (0-369)	0.06
4 year-olds	1 (0-3)		18.5 (0-369)	
5 year-olds	0 (0-2)		0 (0-13)	
6 year-olds	0 (0-1)		0 (0-9)	
7 year-olds	0 (0-1)		0 (0-57)	
8 year-olds	0 (0-2)		0 (0-53)	
Moving belt behind back				
All children	0 (0-1)	0.13	0 (0-244)	0.13
4 year-olds	0 (0-1)		0 (0-244)	
5 year-olds	0 (0-0)		0 (0-0)	
6 year-olds	0 (0-0)		0 (0-0)	
7 year-olds	0 (0-0)		0 (0-0)	
8 year-olds	0 (0-0)		0 (0-0)	
Moving belt-other				
All children	0 (0-1)	0.48	0 (0-51)	0.48
4 year-olds	0 (0-1)		0 (0-51)	
5 year-olds	0 (0-0)		0 (0-0)	
6 year-olds	0 (0-0)		0 (0-0)	
7 year-olds	0 (0-0)		0 (0-0)	
8 year-olds	0 (0-0)		0 (0-0)	
Other Errors (total)				
All children	0 (0-7)	0.08	0 (0-38)	0.08
4 year-olds	0 (0-7)		0 (0-38)	
5 year-olds	0 (0-0)		0 (0-0)	
6 year-olds	0 (0-3)		0 (0-11)	
7 year-olds	0 (0-0)		0 (0-0)	
8 year-olds	0 (0-0)		0 (0-0)	

Table 3 note. P values produced from Kruskal-Wallis tests.

DISCUSSION

Children who are younger may be physically compatible with booster seats, but not mature enough to use them appropriately. Despite meeting weight and height requirements outlined in a commercially available booster seat's manufacturing guidelines, on average 4-year-old children in this sample spent the majority of a simulated drive improperly restrained. In comparison, children who were restrained in harnessed seats spent 100% of the time properly restrained, and children between the ages of 5-8 years spent more than 70% of the time properly restrained/seated. These findings highlight the importance of delaying the transition from a harnessed seat to a booster seat, and is similar to studies observing older children that have found that children under the age of 8 years spend more time in unsafe positions than children aged 8 years or older, regardless of the type of restraint used.[12,13] Additionally, there were wide ranges within our age categories suggesting that individual child differences should be highlighted in guidance given to caregivers about their child's compatibility with various restraint systems.

There are many potential reasons why older children spent less time in unsafe positions, including behavioral or psychological maturity (e.g., increased capacity to control impulses, higher inhibitory levels) and seat comfort/design,[14] however there is limited evidence linking these factors to observed child passenger behaviors. Future work is needed in this topic to determine what balance of physical and psychological factors are appropriate to consider when discussing whether it is time to transition a child into a booster seat. This decision could at times be complex-for example, heavier, younger children may reach engineering limitations of LATCH and vehicle belt systems required to successfully couple a harnessed seat into a vehicle during a crash, but not mature enough to appropriately sit in a booster seat throughout a trip. To date, there is little to no information to accurately inform this balance.

This study is one of the first to directly observe safety related behaviors during the developmental period during which most children are transitioned from harnessed seats to belt positioning booster seats. Engineering limitations (e.g., comfort, design, usability, weight requirements/limits) of CRS is important when guiding caregivers throughout stages of child passenger safety; however, these findings suggest that it may also be critical that primary sources of information, like child care centers, Primary Care Physicians, and CPSTs, also instruct caregivers about important psychological or behavioral factors that likely play important roles in a CRS's effectiveness.

Limitations, Strengths, and Future Directions

The study had a small sample that was skewed towards younger children, with only three 8 year-olds. Immersive simulator methods were used to maximize internal validity, and thus future work is needed in complement to characterize children's behaviors in real-world vehicle trips. The simulated trip time varied across children; this could potentially vary the number of error events coded across videos. Strengths of this study include a diverse sample and a systematic observational protocol with strong interrater reliability scores between coders, as well as a focus on younger children that have not been directly observed before. Because of our use of a small convenience sample, we did not explore differences across individual child characteristics. Child behavior research in other contexts (e.g., playgrounds) has found several child-level variables related to higher injury risks,[15–17] including being a boy,[18,19] and having learning disabilities or a diagnosis of ADHD.[20–22] Despite this evidence, little work has been done to connect how these child-level factors may influence a child passenger's injury risk in MVCs. For example, children with higher levels of impulsivity and activity levels, and lower levels of inhibitory control may object to restraints more than other children. Future work should continue to explore child characteristics, such as personality and temperament, affect child passenger safety behaviors, and expand these findings to more natural trip environments.

CONCLUSION AND PRACTICAL APPLICATIONS

While this study was designed to address potential gaps in the best practice guidelines for the United States, there are direct implications for child passenger safety internationally. Our results indicate the need for research to continue to examine human and psychological factors that serve as precursors to ineffective CPS behaviors. Importantly, premature transitions between CRS may arise out of conflicting messages presented from best practice guidelines, legislation, and seat manufacturer’s guidelines, as well as a lack of information about appropriate behaviors needed from children for CRS to be effective. For example, a caregiver can be compliant with laws or manufacturer guidelines, and not be within the current best-practice guidelines, or may follow manufacturer’s guidelines and transition his/her child to a booster seat earlier than their child can appropriately use one. Therefore, primary sources of information should uniquely consider the needs and capabilities of each child and family when advising caregivers about CRS transition points. To do this effectively, more research is needed that identifies what child-specific traits may lead to inappropriate or risky CPS behaviors. Additionally, in the United States best practice guidelines could be altered to guide caregivers in selecting a seat based on height and weight manufacturer guidelines as a starting point, and to further tailor the type of seat (booster vs harness) based on how well their child is able to stay seated in the correct way, or as the seat was safety-tested.

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Table

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