5-6-2021

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Recommended Citation

Patrice D. Tremoulet, Aditya Belwadi, Brendan Corr, Shreyas Sarfare, Tom Seacrist, Sophia Tushak, How do novel seat positions impact usability of child restraints?, Transportation Research Interdisciplinary Perspectives, Volume 10, 2021, 100372, ISSN 2590-1982, https://doi.org/10.1016/j.trip.2021.100372..

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Transportation Research Interdisciplinary Perspectives 10 (2021) 100372

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

How do novel seat positions impact usability of child restraints?

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ARTICLE INFO

Keywords:
Autonomous vehicles
Child restraint systems
Child passengers
Usability
Human factors

ABSTRACT

Autonomous driving technology and changes in regulations may create an environment that allows novel vehicle interiors. It is important to consider impact on all types of passengers when contemplating interior design, particularly for vehicles that may be used by families with children. We developed a fixture that enables us to change the orientation of each of 4 car seats and used it to simulate three different vehicle interiors. Ten families with children aged 3 months to 7 years interacted with each of the simulated interiors as part of a usability study. Times to install and remove child restraint systems were not significantly different across the three simulated vehicle interiors, but parents were able to release children fastest when using the "X" configuration, which had all seats on a diagonal facing the middle of the vehicle. While overall experience ratings didn't differ significantly, seven out of ten parents indicated that they liked the "X" configuration better than the other two configurations tested. Reasons included: ability to interact with other passengers, ability to see the road, and legroom/comfort. However, many participants disliked having some passengers not facing forward. Overall, parents liked facing their children, but several said that they would only be comfortable if they could see out of the front windshield; meanwhile, children liked seeing their parents' faces but also preferred to face forward. Child restraint system and vehicle manufacturers could benefit from considering this study when designing new products.

Introduction

Autonomous driving technology and changes to current regulations may create an environment that allows different interiors than those found in traditional automobiles. In fact, interior design may serve as an important discriminator for autonomous vehicles (Pettersson, 2017; Strömberg et al., 2018; Lee et al., 2020; Schartmüller et al., 2020). Today, most interior seats are positioned to face the front of the vehicle. Exceptions include London taxis with some rear-facing seats, city buses with some interior-facing seats, rear-facing "third row" seats in mini-vans and sport utility vehicles, and motorhomes that allow passengers to face one another, perhaps across a table. While some autonomous vehicle (AV) users will prefer interior designs that are customized to facilitate working, others may desire interiors that facilitate increased interaction among passengers. Some vehicle owners will demand AVs than can be configured to support either type of use case. For example, most parents want vehicles that can be used both for family transport and solo commuting. Moreover, even if fewer adults chose to own vehicles because ride sharing becomes more universal, there will still be many occasions where entire families need to travel together locally. In short, vehicles that will be used for ridesharing should be able to accommodate not only solo commuters who want to work while riding but also families with young children that need to travel from an airport to a vacation destination.

However, most of the renderings of possible AV interiors that have been published in popular media appear to be tailored to support solo adult passengers or pairs of adults who want to work, relax, or access infotainment (Eddington, 2016; Trego, 2018; Moldenhauer, 2019; Ravenscroft, 2019; Brown, 2020); not only do these design concepts seem to be incompatible with transporting families with young children, many seem potentially unsafe. For example, installing seats around a central table surface may seem appealing, but this sort of interior design invites placement of objects such as cups, toys, tablets and phones which could become dangerous projectiles if the vehicle is hit. Vehicle manufacturers must consider passenger comfort,

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https://doi.org/10.1016/j.trip.2021.100372
Received 20 October 2020; Revised 6 April 2021; Accepted 13 April 2021

regulations, feasibility, and safety implications, as well as passenger preferences, when contemplating different interior design possibilities (Jorlöv et al., 2017; Östling and Larsson, 2019; Nie et al., 2020; Stanglmeier et al., 2020).

It is not only the popular media which has concentrated predominantly upon adult passengers when contemplating AVs. The relatively small number of studies in the autonomous vehicles space that have considered child passengers have focused primarily upon unaccompanied child passengers (Van Ort and Scheltes, 2017; Litman, 2018; Lee and Mirman, 2018; Tremoulet et al., 2020; Koppel et al., 2021). Those studies indicate that many parents would be hesitant to allow even children that they deem mature enough to be left home alone to ride alone in AVs (Lee and Mirman, 2019; Tremoulet et al., 2020; Koppel et al., 2019). This suggests that as AVs start to become more widely used, it will be more common for parents and children to ride together than for children to ride alone. However, although the Federal Highway Administration's National Household Travel survey indicates that in 2016 children under 16 rode in vehicles an average of 25 miles per day (National Household Travel Survey Program Final Report, 2017), scenarios in which young children ride along with their parents in AVs have received very little attention. In particular, it is unclear how non-traditional seating configurations would impact family use of AVs. Several currently open questions include:

- How hard is it to install different types of restraint systems in vehicles with different seating configurations?
- How comfortable are children and parents when using child restraint systems installed into seats facing different directions?
- How hard it is to remove restraint systems that have been installed in vehicles with different seating configurations?
- Should certain seats be designed especially for child occupants (e.g. chairs that don't fully swivel)?
- How do we ensure that using child restraint systems with seats in non-traditional orientations within vehicles will be safe for children? Or, alternatively, should some seats be restricted from some child uses, much like front passenger seats are today?
- Will AVs need special equipment, e.g. new types of child restraint systems, to address young children's needs?

As a first step toward addressing these questions, we conducted a usability study that assesses how easily parents can install and remove existing child restraint systems (CRS) in three simulated vehicle interiors, each of which features at least two seats positioned non-traditional orientations (all seats side-facing, two seats rear-facing, all seats angled inward to face the center of the interior, See Fig. 5). In addition, we asked parents to secure their children into their CRSs after installing them into the simulated interiors and then secure themselves into another seat, to help assess how comfortable parents and children are with children restrained in a static installation. We also asked parents to leave their children restrained and secure themselves into a different seat, so they could experience both sitting across from, and sitting next to, their children while secured in the simulated interiors. Our exploratory usability study does not address how seat orientation relative to the front of the vehicle impacts passenger safety, e.g. the impact of sudden stops or collisions. Several other researchers are exploring this important topic (Filatov et al., 2019; Grébonval et al., 2020; Jin et al., 2018; Matsushita et al, 2019; Rawska et al., 2019; Koopman and Wagner, 2017, 2018; Zhao et al., 2020; Wu et al., 2020).

Methods

Recruitment

We posted information about our study on Children's Hospital of Philadelphia (CHOP)'s research finder website, hung flyers outside the CHOP cafeteria, and emailed parents who had indicated they would be willing to participate in research studies. A study coordinator screened respondents for eligibility. Parents had to have normal or corrected to normal vision and hearing, be fluent in English, and be willing to bring at least one child less than 8, who would also participate, along. Up to four family members, with one parent and one a child less than 8 could participate together. Families were compensated the same amount regardless of how many family members participated.

Participants

Ten families that had at least one child aged less than eight participated in the study (Table 1).

Analysis preparation

Video recordings of the test sessions were used to verify CRS installation and removal times, to capture signs of frustration or confusion and to transcribe comments about simulated interiors. All survey responses were exported from RedCap into Excel, and any comments captured through video reviews were added. Then the PI used comments from three randomly selected usability testing sessions to develop a codebook. Finally, the PI coded all comments from all ten sessions.

Apparatus

Child restraint systems. Four restraint systems, provided by Graco, included a rear-facing infant seat, a convertible infant seat, a tall back booster seat and a low back booster seat.

Configurable seating fixture. A fixture that permitted investigators to manually reconfigure the orientations of each of four car seats featured an aluminum T-slotted rail system divided into four equal quadrants that enabled a car seat to be translated independently along the diagonal (See Fig. 1). A steel swiveling mechanism traditionally used for boat seats was attached underneath each of the four seats enabling them to be rotated independently in 45 degree increments. Four 2008 Chrysler Sebring front row seats, which included integrated seatbelts, were purchased through Ebay. Transparent vinyl sheets were installed on the top of the fixture and on the sides to simulate the vehicle roof and the interior walls (See Fig. 2). Experimenters repositioned seats individually using the lever attached to the swiveling mechanism to stimulate different vehicle interiors (See Fig. 3).

Simulated vehicle interiors. The fixture floor was elevated 13″, the height of the floor of a Chrysler Town & Country minivan, and it was encapsulated in a frame that mirrored the dimensions of the interior of this vehicle: 75″ long × 72″ wide × 52″ tall. Support structures under the fixture floor increased stability and safety (See Fig. 4). Lightweight, transparent plastic sheeting was hung on the frame to give participants a sense of the sides and the ceiling of the simulated vehicle without reducing light for participants and visibility for experimenters. By reconfiguring the seats attached to the fixture, the research team simulated three different vehicle interiors: Front-Facing-Back (FFB), Sides-Facing-In (SFI), and diagonally-facing in (X) (See Fig. 5).

Table 1
Participant Demographics.

Parents	Female	Male
Total participants	10	0
Age range	26–41 yrs	n/a
Mean ages	34.21 yrs	n/a
CHILDREN		
Total participants	12	
Age range	3 mo–7 yrs	
Mean ages	3.7 yrs	

Fig. 1. Rail system enabling team to chane configurations of four car seats.

Fig. 2. Fixture with seats arranged in an “X” configuration.

Fig. 3. Rail system with pedestals that allow seats to be rotated as well as translated.

Procedure

All usability testing sessions were facilitated by two experimenters. One focused on interacting with participants and the second focused on interacting with equipment and timekeeping. In preparation for each session, the experimenters configured the fixture to simulate the first interior specified by a randomly-generated order that had been pre-assigned to the testing session.

Usability testing session. Once families arrived, they were escorted to the testing room, where the experimenters explained the study, parents completed consent forms, and experimenters identified the CRS (s) appropriate for the children based upon height, weight, and age. When the parent indicated she was ready to begin, she was directed to install the CRS(s) into any of the 4 seats, then harness the child participant(s) securely into the CRS(s), and finally secure herself in any desired seat.

Once all participants were secured, an experimenter started playing a video on a screen mounted on the front wall, which simulated riding down a rural road inside a vehicle. The experimenter then directed the parent participant to interact with the child(ren). After two minutes, the experimenter stopped the video and instructed the parent participant to move to another seat in

Table 2
Average times, in seconds, spent on different parts of the usability testing sessions.

Avg time (seconds)	FFB	SFI	“X”
Install CRS	109.30	81.16	65.06 n.s.
Secure child	58.84	47.40 n.s.	54.62
Interaction	349.65	337.89 n.s.	341.26
Release child	34.94	19.72, $p = 0.33$	20.12
Remove CRS	28.46	21.21 n.s.	25.81
Total session	581.19	507.39	506.87 n.s.

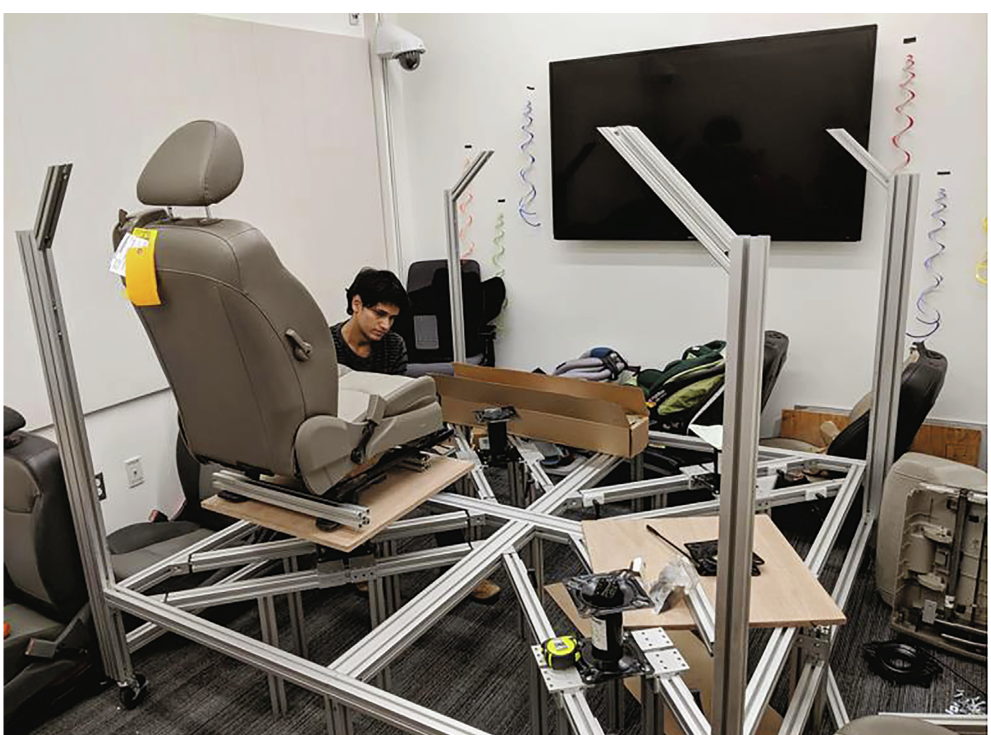

Fig. 4. Fixture frame, mirroring dimensions of Chrysler Town & Country Minivan.

Table 3
Averages of 10 parents' ratings, on a 1 to 5 scale, of their experiences using each of the three simulated interiors.

Configuration	FFB	SFI	"X"
Installation experience	4.8	4.2	5.0 n.s.
Securing experience	4.9	4.4	4.9 n.s.
Interaction experience	4.6	4.0	4.9 n.s.
Removal experience	4.9	4.2	4.9 n.s.
Confidence	4.7 n.s.	4.2	4.6

Table 4
Averages of 10 ratings, on a 1 to 5 scale, of children's overall experience and how safe they felt when sitting in each of the simulated interiors. Ratings for toddlers were provided by parents. No ratings were given for infants.

Configuration	FFB	SFI	"X"
Overall experience	4.5	3.3	4.6 n.s.
Safety	4.7 n.s.	3.6	4.4

Table 5
Reasons parents said they had high confidence they installed CRSs correctly.

Reason	FFB	SFI	X
Experience	3	1	1
Read instructions	2	1	0
Use similar model	2	4	3
Inspected	3	3	6
Easy to install/no difficulties	1	2	0

Table 6
Reasons parents had low confidence they had installed CRSs correctly.

Reason	FFB	SFI	X
A little difficult	1	0	0
Typically use LATCH	0	3	1
Fussy child	0	1	0
Unsure it was installed right	0	1	1

the fixture, while the child participant(s) stayed in the original seat(s) selected. This enabled the parent to experience how comfortable she felt both while seated across from and while seated next to, her child(ren). Then the experimenter started the video and directed the parent to interact with the child(ren) again. After another 2 min the experimenters instructed the parent participant to unharness herself, release the child participant(s), and remove the CRS(s).

After all children were released, the parent was instructed to fill out a reaction survey about the seating configuration. Children aged 5–7 were invited to fill out a child reaction survey using the same tablet that parents used for their reaction surveys. One experimenter stayed with the participants while surveys were filled out. Meanwhile, the second experimenter manipulated the fixture to set up the next seating configuration to be assessed.

The surveys were administered using RedCAP running on a tablet. Parent reaction survey questions included: How difficult was it to install the child restraint system(s) in this simulated interior? How difficult was it to secure your child(ren) into the restraint(s) in this simulated interior? How comfortable were you interacting with your children in this simulated interior? How difficult was it to remove the child restraint system(s)? How confident were you that you installed the child restraint system(s) correctly in this simulated interior? Why did you give that confidence rating? How well did you like this simulated vehicle interior? What did you like most about this simulated vehicle interior? What did you like least about it? Do you have any additional comments about what you liked or disliked? Do you have any suggestions about how changes that could make the interior better? Child reaction survey questions included: How comfortable were you when seated? Did it feel like you would be safe riding in your car seat?

The entire process, from installing the CRS(s) through filling out a reaction survey was repeated twice more, so that each family tested all three seating configurations. Then the parent filled out a final survey which included demographic questions as well as asking which configuration the parent liked best and which she liked least. All verbal children were invited fill out a final survey in the presence of the parent. In several cases, the parent elected to fill out the child survey on behalf of younger children. The testing sessions lasted between 60 and 120 min.

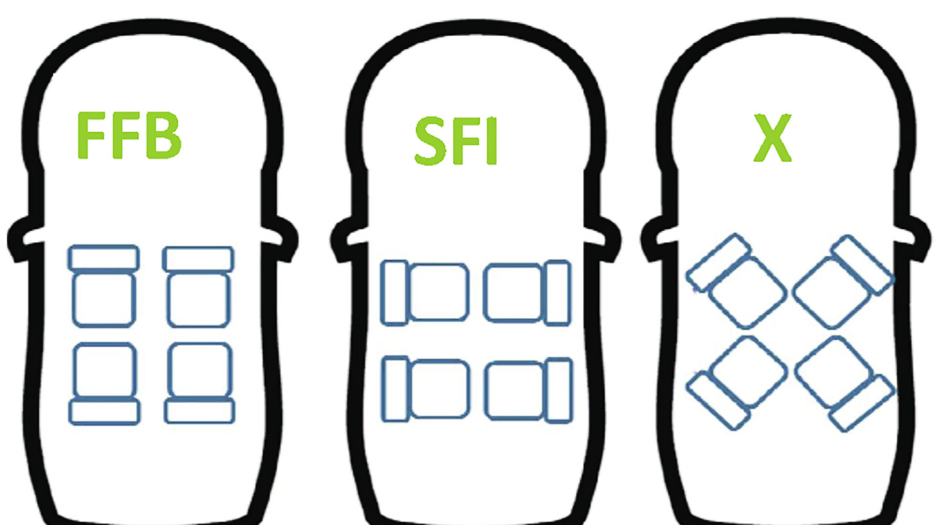

Fig. 5. Three simulated vehicle interiors, achieved by rotating the seats mounted upon the test fixture. To the left is the Front-Facing-Back (FFB) configuration, with the rear seats positioned as they are in conventional vehicles and the front seats rotated 180 degrees. In the middle is the Sides-Facing-In (SFI) configuration, with all seats rotated 90 degrees so that the seat backs are closest to the nearest side window. To the right is the X configuration (X), with the front seats rotated 135 degrees inward and the rear seats rotated 45 degrees inward. Figure modeled after Jorlöv, Bohman, and Larsson (2017).

Findings

The average amount of time, in seconds, that it took for parents to install child restraint systems, secure their children, release their children, remove the child restraint systems, as well as average amount of time spent interacting while all family members were secured and the average total session time, for simulated interiors containing each of the three different configurations are shown in Table 2. Note that booster seats did not require installation and children using them could often release themselves, so the installation and removal times were driven by non-booster CRS. Repeated measures one way analysis of variance (ANOVAs) were not significant for installation times, $F(2,27) = 1.11$, $p = 0.320$; times to secure children, $F(2,27) = 0.127$, $p = 0.730$; interaction time, $F(2,27) = 0.245$, $p = 0.632$; and times to remove CRS, $F(2,27) = 0.469$, $p = 0.511$; and total session times, $F(2,27) = 1.163$, $p = 0.328$. The time to release children from CRSs was significantly lower for X and SFI than for the FFB configuration, $F(2,27) = 6.308$, $p = 0.033$; Tukey's HSD between FFB and SFI = 17.22, $p = 0.04$; Tukey's HSD between FFB and X = 16.82, $p = 0.045$.

One-way ANOVAs with testing order (1st, 2nd, or 3rd) as the independent variable revealed that the order in which configurations were tested did not significantly affect times to perform any task. For installation times $F(2, 27) = 1.356$, $p = 0.275$; for times to secure children, $F(2,27) = 1.010$, $p = 0.378$; for interaction times, $F(2,27) = 0.184$, $p = 0.833$; for times to release children from CRSs $F(2,27) = 1.065$, $p = 0.359$; for times to remove CRS, $F(2,27) = 0.332$, $p = 0.720$, and for total session times $F(2,27) = 0.899$, $p = 0.423$.

Ratings of parents' experience installing CRSs, securing children into CRSs and removing the CRSs were collected on a 1–5 scale with 1 being very difficult and 5 being very easy. Experience interacting with children while secured was also rated on a 1 to 5 scale with 1 being very uncomfortable and 5 being very comfortable. Finally, parents' confidence that CRSs were installed correctly was rated on a 1 to 5 scale, with 1 being not confident at all and 5 being very confident. Average experience ratings are shown in Table 3. The ratings data for each experience and confidence were compared across the three different configurations using Friedman tests. None of the average ratings were significantly different across the three seating configurations: for parents' installation experiences Chi-squared(2) = 4.00, $p = 0.135$; for parents' experiences securing children into CRSs Chi-squared(2) = 1.60, $p = 0.449$; for parents' experiences interacting with children while all family members were secured, Chi-squared(2) = 3.34, $p = 0.179$; for parents' removal experiences Chi-squared(2) = 3.00, $p = 0.223$; for parents' confidence they installed CRSs properly, Chi-squared(2) = 3.60, $p = 0.165$.

The child preference survey asked participants to rate, on a 1 to 5 scale, how comfortable children were while sitting in the simulated interior and how safe they felt while sitting in the simulated interior. Average ratings for each interior are shown in Table 4. Friedman tests indicated that none of the ratings were significantly different across different seating configurations: for overall experience, Chi-squared(2) = 1.103, $p = 0.576$; and for safety Chi-squared(2) = 1.312, $p = 0.519$.

Qualitative feedback from participants

Conventional content analysis methodology, in particular an inductive, open coding approach (Hsieh and Shannon, 2005), was used to analyze both responses to open-ended survey questions and additional comments about the different simulated vehicle interiors that were captured through video reviews. In the summary below, the themes found in parent comments about each simulated vehicle are listed in order of most frequently cited to least frequently cited, and the number of times each theme was mentioned are shown in parentheses. We only intended for children old enough to read and answer questions independently to fill out the child surveys, but parents of younger children often elected to answer the child survey on their child's behalf. Hence for child feedback, after each theme two numbers are shown in parentheses. The first number indicates how many times that theme was mentioned by children and the second indicates how many times the theme was mentioned by a parent who filled out a survey on their child's behalf.

Front-Facing-Back (FFB) configuration

Three of ten parents liked the FFB configuration best and three of ten liked it least. Reasons parents said they liked the FFB configuration include: ability to face child (7), Space/comfort (4), ability to see the road (2), it was possible to face forward as in a traditional vehicle interior (1), and flexibility on how to face child (1). The things parents disliked about this configuration include: Not seeing the road/uncomfortable trusting the vehicle to drive (6), not enough legroom (4), children could kick others (2), sitting backwards (2), concern about motion sickness (1), difficulty using CRS (1), and "it didn't feel safe" (1).

Things children liked about the FFB configuration included: ability to see/interact with parent (3/2), space/comfort (2/2), ability to see the road (1/1), "it was fun" (1/0), and "it was easy to get in and out" (1/0). Things children did not like about this configuration included: inability to see out the front/not comfortable trusting the vehicle to drive (1/1), difficulty using CRS (1/0), "my mother could see me the whole time" (1/0), facing backwards (1/0), and not enough space (1/0).

Sides-Facing-In (SFI) configuration

None of the parents liked the SFI configuration best, and seven of ten liked it least. Positive parent feedback about this configuration included: ability to interact with child (5), could see out front from any seat (3), ability to see both road and child (2), and ability to sit in any direction(1). Negative feedback included: it felt cramped (8), concern about motion sickness (4), children could kick others (3), sitting sideways (2), it felt unsafe (1), it was the least social (1), fear of motion sickness (1), "My child liked sitting in the driver's seat" (1) and "My children felt safe."

Things that children liked about the SFI configuration included: ability to see parents (4/0), ability to interact with parents (2/1), space/comfort (1/0), being close to the front of the vehicle (1/0), having 'my own seat' rather than a bench (1/0). Things they did not like about it included: difficult to use booster (1), felt cramped (2/3), didn't feel safe (1).

X configuration

Seven of ten parents liked the X configuration best and none liked it least. Reasons parents liked this configuration include: ability to interact with child(ren) (7), space/comfort (7), ability to see both the road and children (6), easy to use CRSs (2), it "still felt like I was in driver's seat" (1), possible to have a child facing front in a rear-facing restraint (1). Things that parents did not like about this configuration include: front passengers can't see the road easily (3), some passengers have to ride backwards (2), children could kick others (1), and concern about motion sickness (1).

Children liked the following about the X configuration: ability to see/interact with parent (5/2), space/comfort (3/2), ability to see the road (2/1), easy to use CRS (1/0), "felt safest" (1/0), and "it was fun" (1/0). They disliked the following: being far from parent (1/0), couldn't see the road (1/0), facing backwards (0/1).

When asked if they had any suggestions that would improve vehicle interiors using the different configurations, parents suggested the following: allowing seats to swivel in the FFB configuration (1); adding more space (3), allowing seats to swivel (2), adding a table (2) and adding a jumpseat (1) to the SFI configuration; and allowing seats to swivel (3), adding a table and jumpseats (1), and providing more legroom (1) in the X configuration.

Finally, when parents were asked to explain why they rated their confidence that they had installed the child restraint system(s) correctly as they had, those who gave high ratings (4 or 5 out of 5) cited experience installing CRSs, that they'd read instructions, that they use a similar model, that they inspected it to verify it was installed correctly, and that it was easy to install. Those who gave low ratings cited the following reasons: they found it a little difficult to install CRS in this simulated interior, they typically use LATCH systems to secure CRSs, their child was fussy/distracting, they were unsure if it was installed correctly. Tables 5 and 6 show the frequency each reason was given for each seating configuration. (Each parent was asked to rate confidence after using each configuration.)

Discussion

Autonomous driving technologies may make it possible for manufacturers to sell vehicles with novel seating configurations, including "living room style" seating, which would enable passengers to interact with one another more easily than they can in traditional vehicles. While being able to face other passengers during AV rides may sound appealing, changing the configuration of seats may impact passenger comfort and safety, particularly when some of the passengers are children. Relatively few discussions about the potential impact of AVs upon modern society have specifically considered child passengers, despite the fact that children typically ride in vehicles several miles each day (Tefft, 2018). Our study represents an important first step in understanding what it would be like for families with children young enough to require restraint systems to use AVs that have living room style seating.

Our usability test revealed that it took approximately the same amount of time to install and remove child restraints in each of the three novel vehicle interiors we simulated. However, it took significantly longer for parents to release children from CRSs in the simulated interior featuring the Front-Facing-Back style configuration compared to the simulated interiors with the Sides-Facing-In and X configurations (See Fig. 5). Seven out of ten parents and five of the eight children who expressed a preference indicated that they preferred the X-configuration, which has all seats on a diagonal, angled towards the center of the vehicle, but this was not a strong preference. Participants cited comfort, ability to face other occupants, and legroom as reasons for this preference. While all three of our simulated interiors enabled occupants to face one another, the one featuring the X configuration made it least likely children would inadvertently kick other passengers' legs. This simulated interior also had more open space close to the simulated side door that participants used to access the interior, which may have influenced parents' perception of how easy it was to install and remove CRSs.

There are several limitations to this work. Our apparatus did not support highly realistic simulations of vehicle interiors; participants had to use their imagination to envision themselves inside of an actual vehicle. They might have perceived themselves to be more cramped if realistic windows and doors had been present. Moreover, since we used four 'front row' seats from relatively old (2008) vehicles, LATCH installation was not an option. In the future, industry-researcher collaborations should get familes' feedback on realistic prototypes of novel vehicle interiors, e.g. with rigid, transparent ceilings, doors, and sides, which could be covered with an opaque sheet to provide a more realistic sense being in a vehicle. The study was also limited because it did not assess usability of the actual CRSs that participating families use in their own vehicles. We expect that our participants' experiences using the Graco CRSs that we supplied are representative of the experiences other families would have using other CRSs, but it is possible that parents would find other CRSs easier or harder to install and/or remove in some or all of the three simulated interiors. Moreover, it is likely that CRSs and vehicle bodies will both be reengineered as autonomous driving technologies mature, which limits the generalizability of our results. Windows and doors may be moved to different locations, and seats may take entirely different forms, e.g. long pods allowing passengers to recline, jumpseat-style benches, etc. Ideally, this re-engineering will not only take families' needs into account but also be collaborative, resulting in new vehicle designs and new CRS designs that, together, enable families to easily, safely and comfortably secure all family members into AVs.

Another limitation of this work is that participants were only asked their preferences among the three simulated interiors that we provided; they were not asked to compare any of these to the traditional all-seats-face-forward configuration found in most vehicles. In addition, only one adult from each family chose to participate in the study. Future work in this areas should also include some families with two adult participants to provided a sense of how comfortable it is for two adults and one or two young children to ride together. It would be particularly interesting to get feedback from adults who sit facing backwards in the FFB and X configurations; while both parents and the children who were old enough to express an opinion, all of whom rode in front-facing CRSs, said they liked being able to face one another in these configurations, many of them also indicated that they preferred to face the front of the vehicle. Finally, our study did not consider how seat positioning could impact passenger safety.

Since the apparatus in this study was not very realistic, it would be valuable have parents provide feedback on using existing CRSs in actual vehicles with non-traditional seating, such as London taxis, which feature Front-Facing-Back seating (see Fig. 5) and buses and recreational vehicles, some of which feature Sides-Facing-In seating (see Fig. 5). Similarly, it would be informative to learn what sorts of activities families currently engage in while riding together in taxis, buses and recreational vehicles, and compare this to what parents say they would envision their families doing while riding together in AVs – both before and after suggesting that one parent might need to be designated as 'co-pilot', ready to take over if needed. This type of information could not only inform the design of more realistic usability tests of novel vehicle interiors but also be helpful to policy makers tasked with establishing guidelines or requirements for restraining children in AVs, including deciding if there should be restrictions on which seats can be used by children.

Despite its limitations, the work presented here illustrates how much can be learned by asking families with young children to interact with low-fidelity models of vehicle interiors. It also highlights how important it is for manufacturers to consider family use when redesigning vehicles and/or restraint systems. Manufacturers who are seriously considering novel interior designs and/or new restraint system designs need to develop realistic prototypes and have families with children to interact with those prototypes. CRS manufacturers would benefit from learning more about parents preferences for ensuring their children can ride safely in AVs. Do they desire CRSs that are simple to install and remove so they can easily travel with the children? Do they prefer built-in boosters that stay in vehicles but restrict child seating locations? Finally, given how frequently both legroom and space were mentioned as factors that influenced participants' preferences for different simulated interiors, vehicle manufacturers should consider conducting usability studies with more realistic configurable prototypes to understand how large interiors need to be (length, width, and height) to avoid having a desired seating configuration make passengers feel cramped.

While vehicle and CRS manufacturers who are contemplating novel designs must consider cost and safety, they need more research exploring how changes to vehicle interiors could impact families with young children so that they can also consider convenience, comfort, and practicality for families when evaluating different design options. In fact, it would be best for families and manufacturers if vehicle and CRS manufacturers could work together to conduct safety and usability tests using realistic prototypes of re-engineered vehicle bodies and realistic prototypes of CRSs designed to be used in those vehicle bodies. In conclusion, this work offers some insights about how vehicle interior design can impact CRS use and passenger comfort, but this study is just a small first step. It is vitally important to conduct additional research exploring how families with young children would interact with AVs, and especially safety studies that assess how alternate seating positions affect the forces experienced by passengers during collisions. This research should inform the development of testing protocols to assist in evaluating novel designs for AVs, and new CRSs intended to be used in AVs to enhance usability of these vehicles for families with young children.

CRediT authorship contribution statement

Patrice D. Tremoulet: Conceptualization, Methodology, Supervision, Formal analysis. **Aditya Belwadi:** Methodology, Resources, Project administration. **Brendan Corr:** Investigation, Data curation. **Shreyas Sarfare:** Data curation, Software, Investigation. **Tom Seacrist:** Resources, Methodology. **Sophia Tushak:** Methodology, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement and funding resources

The authors would like to acknowledge the National Science Foundation (NSF) Center for Child Injury Prevention Studies at the Children's Hospital of Philadelphia (CHOP) and the Ohio State University (OSU) for sponsoring this study and its Industry Advisory Board (IAB) members for their support, valuable input and advice. The views presented are those of the authors and not necessarily the views of CHOP, OSU, the NSF, or the IAB members. While designing the study, the research team benefited from valuable advice and contributions of the following IAB project advisors: Suzanne Johansson, Julie Kleinert, Doug Longhitano, Uwe Meissner, Mark Neal, Schuyler St. Lawrence, Jennifer Stockburger, Jerry Wang, and Arjun Yetukuri. The entire IAB had opportunity to review this manuscript and suggest edits prior to submission for publication. The research team would also like to thank Jalaj Maheshwari for helping with fixture creation and helping to run participants, and Kevin Heller for providing outstanding administrative support and team coordination.

Funding: This work was supported by the National Science Foundation (NSF) Center for Child Injury Prevention Studies at the Children's Hospital of Philadelphia (CHOP) and the Ohio State University (OSU) Grant numbers 1539938 and 1650541.

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