THE EFFECT OF ISOFIX ON BOOSTER SEAT PERFORMANCE IN UN REGULATION NO. 129 FRONT IMPACT TESTS

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ABSTRACT

ISOFIX was conceived as an alternative to the seat belt for installing integral child restraint systems (e.g. harness seats). However, ISOFIX-like attachments are now offered on some non-integral child restraints (booster seats). In such cases, the booster seat is attached to the car using the ISOFIX anchorages, with the child secured by the seat belt. This is usually provided as a 'comfort feature' to assist in the positioning of the booster seat and to ensure it is secure in the event of a crash when unoccupied. ISOFIX is not thought to convey significant safety benefits (or disbenefits) for children in booster seats; however, very little research has been carried out. The aim of this study was to investigate the effect of ISOFIX on booster seat performance in front impact. The paper presents a series of sled experiments using fully instrumented Q-Series dummies. The same booster seat was used in all experiments, but it was installed in one of four conditions: no ISOFIX attachments; ISOFIX fitted, but stowed away; ISOFIX used with deformable attachments (that allowed the booster seat to translate, while remaining attached); ISOFIX with fixed attachments (with no translation of the booster seat). The frontal impact test procedure specified in United Nations (UN) Regulation No. 129 was followed in all experiments.

ISOFIX generally had marginal effects on the performance of the booster seat in these tests. However, pelvis displacement (with respect to the booster) was greater with fixed ISOFIX attachments. In this condition, the dummy and the booster seat were less well coupled, compared with the other installation modes, but submarining was not observed. Measurements associated with compressive loading of the torso (i.e. chest deflection and abdomen pressure) were expected to be lower when ISOFIX was used (based on previously reported tests), but this was not observed uniformly. Effects of the dummy design, such as head-to-chest contact and diagonal belt slippage may have influenced its sensitivity to differences in booster seat installation modes. Nevertheless, deformable ISOFIX attachments appeared to offer the benefit of ensuring the dummy and booster seat were coupled together throughout the impact, while reducing the potential for compressive loading to the torso.

These findings suggest that the current practice of offering consumers a choice with respect to the provision of ISOFIX on booster seats is appropriate. UN Regulation No. 129 is being amended to include booster seats. They can be approved with or without ISOFIX attachments, but where present, they must be stowable. This study supports this philosophy; however, it was based on one booster seat only (installed in different attachment modes). Different trends might be observed in other booster seats. Furthermore, this study focussed on front impact. Other impact directions (such as side impact) might yield different results.

INTRODUCTION

ISOFIX is a harmonised system for installing a child restraint system to a car. It comprises two vehicle anchorages with two corresponding attachments on the child restraint. These are typically used together with a means to limit the pitch rotation of the child restraint into the seat cushion (i.e. a top tether or a support leg). ISOFIX was conceived as an alternative to the seat belt for installing integral child restraints (in which the child is restrained by a harness or shield coupled to a supplementary child seat) (Turbell et al., 1993). However, ISOFIX-like systems are now offered on some non-integral child restraints (i.e. booster seats, that raise the child to improve the fit and position of the adult seat belt over the child's body). In such cases, the booster seat is attached to the car using the ISOFIX anchorages, with the child secured by the seat belt. This is usually provided as a 'comfort feature' to assist in the positioning of the booster seat and to ensure it is secure in the event of a crash when unoccupied.

United Nations (UN) Regulation No. 129 (on Enhanced Child Restraint Systems) came into force in June 2013. It aims to improve the safety of child restraints and reduce their misuse by promoting ISOFIX (United Nations Economic Commission for Europe, 2016). Initially, it applies only to integral ISOFIX child restraint systems, but will eventually include all child restraint types. For instance, it is currently in the process of being amended to enable the type-approval of booster seats. At the start of this process, it was expected that booster seats would also be required to have ISOFIX (Terms of Reference for phase 2 and phase 3, 2011). However, this restriction was removed, in part due to difficulties in agreeing a universal ISOFIX solution among the stakeholders (and the observation that ISOFIX may not offer performance advantages for these child restraints or reduce their misuse) (Status report GRSP IWG ECRS, 2013). The regulation will therefore allow booster seats to feature ISOFIX, but they must be stowable for the seat to qualify as a universal system.

Although ISOFIX is not thought to convey any significant safety benefits (or disbenefits) for children in booster seats, very little research has been carried out. Studies of the performance of booster seats in real-world collisions do not typically include ISOFIX boosters, or if they do, they do not distinguish them from belt only models (Wismans et al., 2008). Nevertheless, while there is always room for improvement, overall, booster seats are very effective in reducing the risk of injury to children in collisions (Arbogast et al., 2007).

Visvikis et al. (2014) found that the use of ISOFIX with a booster seat did not influence its performance greatly in front impact tests with the Q3 and Q10 dummies. Nevertheless, there appear to be very few laboratory crash studies reported in the literature. During the aforementioned regulatory discussions, a group of child restraint system manufacturers combined anonymised data from unpublished internal tests (European Association of Automotive Suppliers, 2015). This found little evidence of a consistent effect of ISOFIX on booster seat performance. In front impact (where slightly more data were available), measurements associated with compressive loadig of the torso tended to be lower when ISOFIX was used, whereas pelvis displacement with respect to the booster seat appeared to be greater. However, the authors acknowledged that further data might reveal different trends. Similarly, Charlton et al. (2007) found that, in side impact, the rigid anchorages of the ISOFIX system reduced the lateral motion of the booster; however, the expected benefits of the rigid attachment in reducing head accelerations were not observed consistently.

The aim of this study was to investigate the effect of ISOFIX on booster seat performance in front impact conditions. It was expected that the study would help to validate decsions made in the development of UN Regulation No. 129, and help inform future decisions, about the regulatory requirements for booster seats.

METHODS

Ten front impact experiments were carried out on a deceleration sled at TRL. TRL is an accredited Technical Service for the type-approval of child restraint systems to UN Regulation No. 129. The tests were performed according to the procedure specified in UN Regulation No. 129, but also took account of the GRSP proposal to extend the regulation to include booster seats[1]. The principal test conditions comprised an impact speed of 50^{+0}_{-2} km/h and a deceleration corridor that peaked between 20 g and 28 g.

[1] ECE/TRANS/WP.29/2016/107 – Proposal for the 02 series of amendments to UN Regulation No. 129 - Adopted by the Working Party on Passive Safety (GRSP) at its 59th session and subsequently adopted by the World Forum for Harmonisation of Vehicle Regulations (WP.29) and the Administrative Committee AC.1 at the 170th session.

The experiments are summarised in Table 1. Three fully-instrumented Q-Series dummies were used; a Q3, a Q6 and a Q10. These dummies correspond to the extremes and mid-point of the stature range likely to be declared for booster seats approved to Regulation No. 129. The set-up for a typical test is shown in Figure 1. All dummies were equipped with production versions of the Abdominal Pressure Twin Sensors (APTS) produced by Transpolis and hip liners produced by Humanetics (see Figure 2). Hip liners are a new dummy accessory to prevent the lap part of the seat belt from becoming trapped in the gap between the legs and pelvis of the dummy.

Table 1.
Test matrix

Dummy	Booster seat installation
Q3	Seat belt only – no ISOFIX on seat
	Seat belt – ISOFIX present but stowed
	ISOFIX used – translating attachments
	ISOFIX used – fixed attachments
Q6	Seat belt only – no ISOFIX on seat
	Seat belt – ISOFIX present but stowed
	ISOFIX used – translating attachments
	ISOFIX used – fixed attachments
Q10	Seat belt only – no ISOFIX on seat
	Seat belt – ISOFIX present but stowed
	ISOFIX used – translating attachments
	ISOFIX used – fixed attachments

The same (series-production) booster seat was used in all experiments, but it was installed in one of four conditions:

1. With the seat belt only – there were no ISOFIX attachments on the booster seat;
2. With the seat belt only – the booster was equipped with ISOFIX, but the attachments were stowed away;
3. With ISOFIX that featured deformable attachments (that allowed the booster seat to translate, while remaining attached to the ISOFIX anchorages on the test bench);
4. With ISOFIX attachments that were fixed (with no translation of the booster seat).

The booster seat with no ISOFIX anchorages was 0.81 kg lighter in this condition, but was identical to the others in all other respects. The booster seat was type-approved to UN Regulation No. 44. It was not developed or optimised for the UN Regulation No. 129 test environment.

Figure 1. Example test set-up (Q6 dummy)

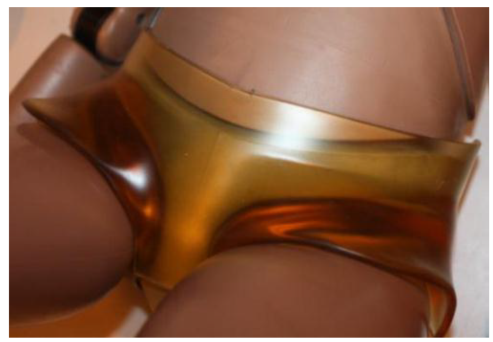


Figure 2. Q-Series dummy hip liner

RESULTS

Translation of the ISOFIX attachments

In one test condition, the booster seat was equipped with ISOFIX attachments that allowed the seat to translate, while remaining attached to the ISOFIX anchorages on the test bench (see Table 1). Unfortunately, the feature did not deploy significantly in the test with the Q3 dummy (see Table 2). Nevertheless, it functioned in the tests with the Q6 and Q10, displaying the greatest translation with the larger dummy.

Table 2.
Translation of the booster seat ISOFIX attachments (measured post-impact)

Dummy	ISOFIX attachment translation	
	Left	Right
Q3	0	5
Q6	12	12
Q10	28	30

A larger dummy mass typically causes a booster seat to tip further into the cushion of the test bench during an impact. When this occurs, the seat base becomes more horizontal, thus improving the conditions for the deformable system featured in these tests to deploy. This might explain the differences shown in Table 2.

Booster seat and dummy kinematics

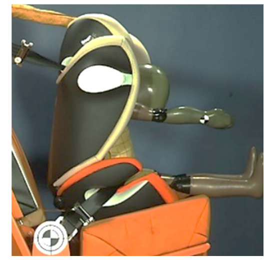
Figures 3, 4 and 5 show the interaction between the booster seat, dummy and seat belt for tests with the Q3, Q6 and Q10 dummies respectively. Each image shows a side view of the booster seat and dummy at, or very close to, their peak forward displacement. Additional, oblique views that highlight the dummy and seat belt interaction are shown in Appendix A.

When the booster seat was installed with a seat belt only, both the booster and the dummy moved into the belt during the impact. This coupling of seat and dummy helped to ensure a good path of the belt throughout the impact. The additional mass of the stowed ISOFIX anchorages did not appear to influence this movement in any significant way.

When ISOFIX was used to secure the booster seat to the test bench, the characteristics of the attachments influenced the seat and dummy kinematics. For instance, some decoupling of the seat and dummy was observed when the attachments were fixed and unable to translate. This was observed predominantly with the Q6 and Q10. These dummies moved into the belt while the seat was held closer to the bench than in the corresponding belt only tests. This can be seen in Figures 4 and 5, where more of the dummy's abdomen and pelvis are visible in this 'fixed attachment' condition. This phenomenon was not observed with the Q3, possibly due to the smaller size and lighter weight of this dummy.

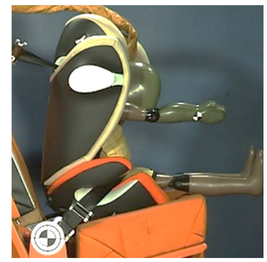
Greater kinematic differences might have been expected when ISOFIX was used, but rotation of the booster seat about the ISOFIX anchorages (and into the seat cushion) gave the impression of greater forward movement of the seat. Nevertheless, the gap between the seat-back of the test bench and the booster backrest was smaller when ISOFIX was used. The translating attachments functioned with the Q10, and to some extent with the Q6, and meant that the movement and coupling of the booster and dummy in this condition was comparable to that of the belt only tests.

Seat belt only – no ISOFIX



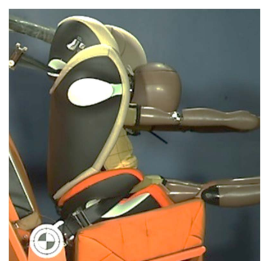
Seat belt only – ISOFIX stowed

ISOFIX used – translating

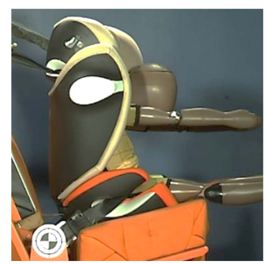


ISOFIX used - fixed

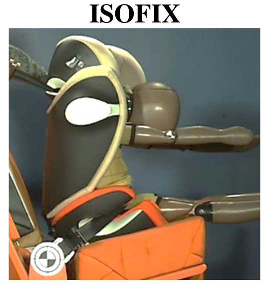
Figure 3. Q3 dummy (90 ms)



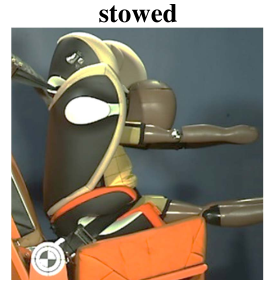
Seat belt only – no ISOFIX



Seat belt only – ISOFIX stowed

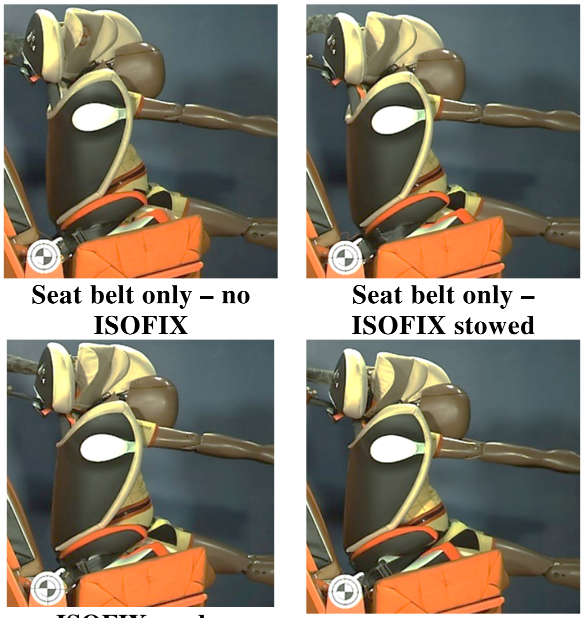


ISOFIX used – translating



ISOFIX used - fixed

Figure 4. Q6 dummy (95 ms)



Seat belt only – no ISOFIX
Seat belt only – ISOFIX stowed
ISOFIX used – translating
ISOFIX used - fixed

Figure 5. Q10 dummy (95 ms)

Although the Q6 and Q10 dummies moved further forwards within the booster seat when 'fixed' ISOFIX attachments were used (compared with other installation modes), the lap part of the seat belt remained on the pelvis. There did not appear to be any greater risk of submarining behaviour, therefore, in these tests. This is illustrated most clearly with the Q10, where this motion was greatest (see Figure A3, Appendix A).

Dummy measurements

Head loading The attachment mode of the booster seat did not appear to influence dummy head excursion (see Figure 6). Although some differences were observed, they were typically within levels expected for normal test-to-test variation and did not provide strong evidence for a trend.

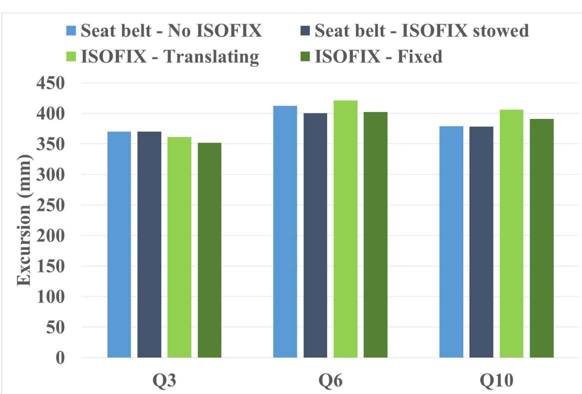


Figure 6. Dummy head excursion

The Q3 and Q6 dummies recorded greater head acceleration (3ms value) when the booster seat was installed with the seat belt only (see Figure 7). This was surprising, given that head excursion was reasonably consistent between the installation modes. These parameters are often related, with higher head acceleration being associated with lower head excursion and vice versa. This was not observed in these tests, which suggests some other effects were involved. For instance, head-to-chest contact was observed with the Q3 and Q6 dummies and was likely to have influenced the head acceleration. This will be discussed later on with respect to chest loading, but might also explain unusual trends in the head response with these dummies.

The head acceleration measurements with the Q10 dummy did not display clear differences between the belt only and ISOFIX conditions. However, the difference of around 10 g between the 'no ISOFIX' and the 'stowed ISOFIX' belt only tests was surprising, given that the only difference between these boosters was an extra 0.81 kg in mass (with stowed ISOFIX). As the 3ms values from the ISOFIX tests were in between these belt attached tests, the overall spread of results suggests that the booster attachment mode did not influence head acceleration greatly with this dummy.

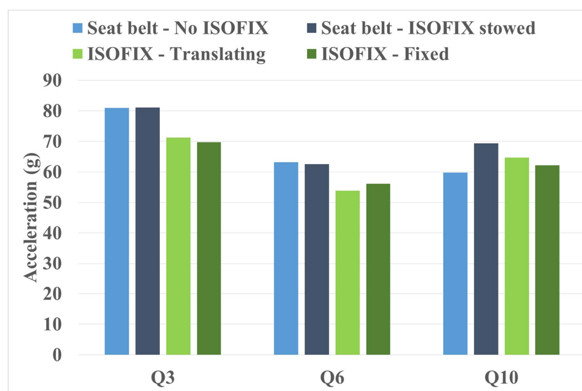


Figure 7. Dummy head acceleration

Neck loading No consistent trends were observed in the upper neck tensile force (see Figure 8). The peak force was very similar across the booster installation modes with the Q3 dummy. Some differences were observed with the Q6 and Q10, but there was little evidence of meaningful variation. Neck tensile force often follows trends observed in the head acceleration. As this does not appear to have been the case in these tests, particularly for the Q3, it further suggests that head-to-chest contact influenced the dummy measurements.

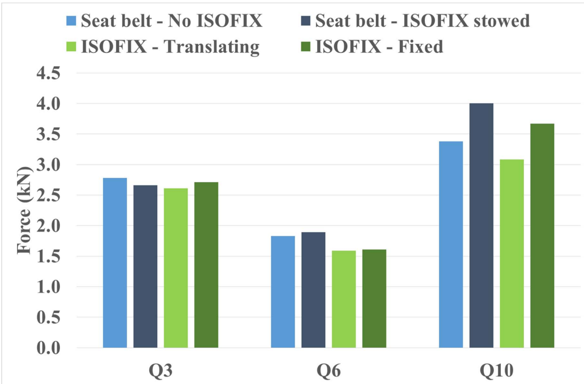


Figure 8. Dummy neck tensile force

Chest loading Resultant chest acceleration (3ms value) did not appear to differ significantly across the installation modes for all dummies (see Figure 9). Although some differences were observed, the level of variation in each case did not provide strong evidence of a trend.

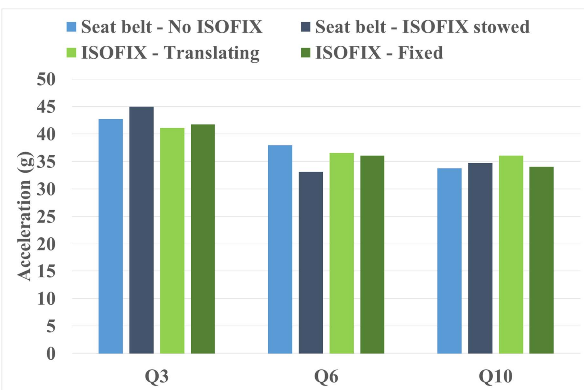


Figure 9. Dummy chest acceleration

The mode of attachment of the booster seat was expected to influence chest deflection more than acceleration. For instance (depending on its mass), a booster that moves forward with the child might be expected to increase compressive loading of the chest, when the child is ultimately restrained by the belt. However, this was difficult to distinguish in these tests (see Figure 10), largely due to features of the dummy and sensor design, particularly for the Q3 and Q6.

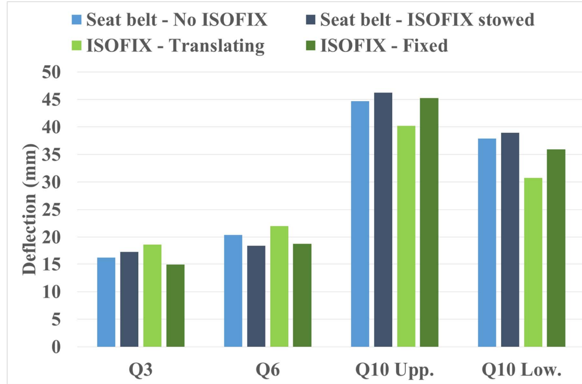


Figure 10. Dummy chest deflection

Although not the main focus for this paper, these dummy and sensor design features were of interest for their effects on deflection measurement. The first point of interest was that the peak deflection measured by the Q3 and Q6 dummies resulted from head-to-chest contact, rather than seat belt loading (see Figure 11 and Figure 12). In each case, the deflection response displayed an initial peak that seemingly coincided with the period of greatest belt loading. This was followed by a second (and greatest) peak that coincided with flexion of the head and neck into the chest. Such degrees of flexion have been observed in cadaver tests (Cassan et al., 1993); nevertheless, the extent to which it produces biofidelic loading of the chest is still a matter for research.

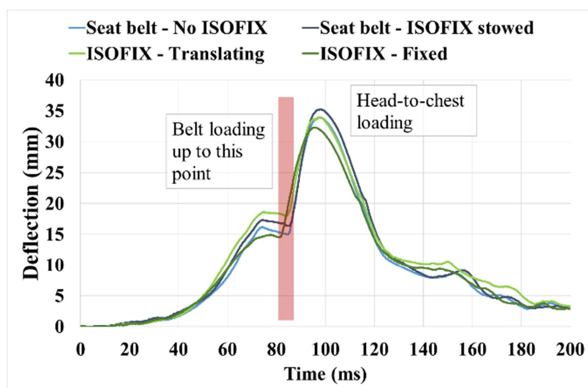


Figure 11. Q3 dummy chest deflection

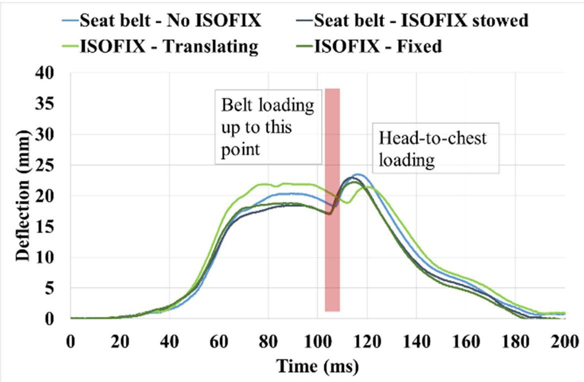


Figure 12. Q6 dummy chest deflection

The ‘peak’ values displayed in Figure 10 exclude the period of head-to-chest loading. Nevertheless, this still does not give an accurate picture of compressive chest loading due to the single point deflection measurement of the Q3 and Q6 dummies. During the impact, the belt moved up the chest and away from the deflection sensor. This meant that deflection was not being measured in the region of loading (see Figure 13). This behaviour has been reported in other tests using the Q-Series dummies as summarised by Wismans et al. (2016). Unfortunately, no solution is readily available and hence care must be taken when interpreting these deflection measurements.

Figure 13. Dummy and diagonal belt interaction

Abdomen loading The lap part of the seat belt remained on the pelvis of each dummy in all booster seat installation modes (see Appendix A). This was reflected in the abdomen pressure measurements (Figure 14), particularly with the Q3 and Q6. In each case, the measurements were very low (0.2 to 0.4 bar) compared with the regulatory threshold for these dummies (1.0 bar). With such low measurements, it was unclear whether differences observed between the installation modes represented real trends. Even if they did, all modes achieved low abdomen pressure, suggesting a very low risk of abdomen injury.

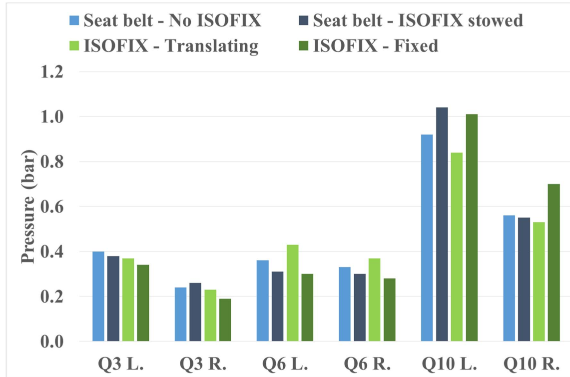


Figure 14. Dummy abdomen pressure

In contrast, the Q10 measured relatively higher abdomen pressure (0.6 to 1.0 bar), compared to its regulatory threshold (1.2 bar), than the Q3 and Q6 dummies. The measurements on the left (buckle) side of the abdomen resulted primarily from the diagonal part of the seat belt. In this case, the greatest pressure was recorded in the belt installation with stowed ISOFIX and in the fixed ISOFIX installation.

The additional mass (0.81 kg) of the booster with stowed ISOFIX attachments, may have increased the tendency for compressive loading to the abdomen. It seems plausible for this to be observed with the Q10 only, as this was the only dummy with which a belt passed over the abdomen sensors (the diagonal belt moved above the abdomen for the Q3 and Q6 dummies and no lap belt loading was observed in any test).

Higher pressure measurement with fixed ISOFIX seems counter intuitive. This booster was held rigidly to the test bench, so less compressive loading was expected. However, this was observed on both sides of the abdomen and seems to indicate a real trend. The decoupling of seat and dummy described earlier may have influenced the abdomen loading in some other way, resulting in this apparent increase in pressure. The translating attachments seemed to help reduce the pressure to levels consistent with the seat belt installation.

DISCUSSION AND LIMITATIONS

ISOFIX had marginal effects on the performance of the booster seat in these tests. However, pelvis displacement (with respect to the booster seat) was greater with fixed ISOFIX attachments. In this condition, the dummy and the booster seat were less well coupled (compared with other installation modes), but submarining was not observed. Measurements associated with compressive loading of the torso (i.e. chest deflection and abdomen pressure) were expected to be lower when ISOFIX was used, based on previously reported tests by the European Association of Automotive Suppliers (2015); however, this was not observed consistently in the tests reported in this paper. Certain aspects of the dummy design, such as its proneness for head-to-chest contact, and the tendency for belt movement away from the (single point) deflection sensor may have masked any trends that might otherwise have emerged between the booster seat installation modes. Nevertheless, deformable ISOFIX attachments appeared to offer the benefit of ensuring the dummy and booster seat were coupled together throughout the impact, while reducing the potential for compressive loading to the torso.

These findings suggest that the current practice of offering consumers a choice with respect to the provision of ISOFIX on booster seats is appropriate. UN Regulation No. 129 is being amended to include booster seats. They can be approved with or without ISOFIX attachments, but where present, they must be retractable and stowable. This study supports this philosophy; however, it was based on one booster seat only (installed with different attachment methods). Different trends might be observed in other booster seats. Furthermore, this study focussed on front impact. Other impact directions (such as side impact) might yield different results.

The UN Regulation No. 129 test bench was designed to be representative of the vehicle fleet. Nevertheless, certain aspects of the bench, and the regulatory test procedure, reflect a need for test repeatability and reproducibility. They are not intended to deliver an exact recreation of the vehicle environment. Differences between the standardised seat belt of the test bench (including the way it is tensioned before a test) and a real seat belt, for example, might have been important for the tests reported here.

CONCLUSIONS

The protection of children in cars is a priority of Governments around the World. Booster seats are very effective in reducing the risk of injury to children that have outgrown other child restraint types. ISOFIX has the primary function to improve the ease of attachment of integral child restraints and therefore the risk of misuse. This study has shown that ISOFIX can be used on non-integral child restraints (booster seats) to assist parents without compromising safety.

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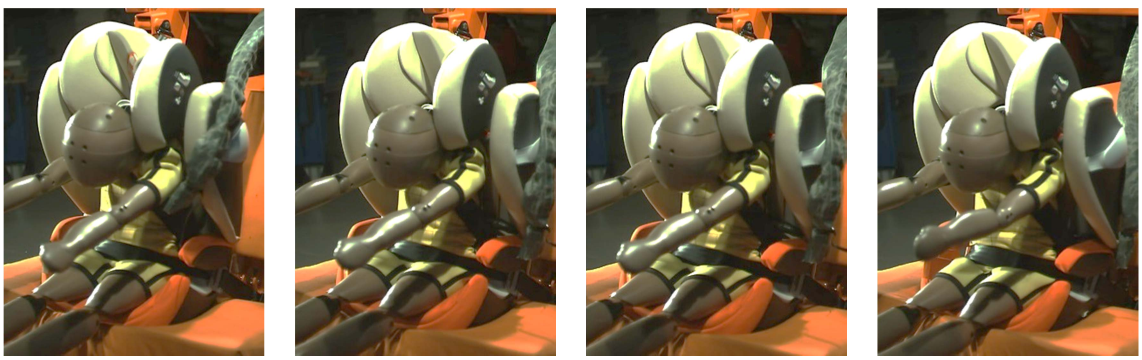
APPENDIX A

DUMMY AND SEAT BELT INTERATION

Seat belt only – no ISOFIX | **Seat belt only – ISOFIX stowed** | **ISOFIX used – translating** | **ISOFIX used - fixed**

Figure A1. Q3 dummy and seat belt interaction (90 ms)



Seat belt only – no ISOFIX | **Seat belt only – ISOFIX stowed** | **ISOFIX used – translating** | **ISOFIX used - fixed**

Figure A2. Q6 dummy and seat belt interaction (90 ms)

Seat belt only – no ISOFIX | **Seat belt only – ISOFIX stowed** | **ISOFIX used – translating** | **ISOFIX used - fixed**

Figure A3. Q10 dummy and seat belt interaction (95 ms)