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Experimental Analysis of the Effect of ISOFIX Child Restraint System's Harness Tension on Child Occupant's Chest Acceleration in Frontal Collisions

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Abstract

The research seeks to ascertain the relation between ISOFIX child restraint system's harness tension and child occupant's chest acceleration in frontal collisions, and analyze the potential risks posed by different harness tensile forces. It is important to verify and validate the effects of harness tensions on child occupants' potential injuries, since child restraint system's user manual does not indicate the extent to which the adjusting belt should be pulled generally, thus making it possible to cause the harness tensile force to be applied arbitrarily. Hence, public awareness of the issue should be improved. A test scheme was devised and conducted to collect necessary information about P1.5 dummy in frontal collisions. The pulling forces applied to the adjusting belts were set at 3 different levels. Chest accelerations were acquired and compared to analyze the effects. Based on test results, the relation was ascertained and validated. Additionally, suggestions were made about adjusting the harness tension and appropriate use of ISOFIX child restraint system.

Abstrak

Analisis Eksperimental Pengaruh Ketegangan *Harness* Sistem Pengaman Anak ISOFIX Terhadap Akselerasi Dada Penumpang Anak-Anak pada Tabrakan Depan. Penelitian ini berusaha untuk memastikan hubungan antara ketegangan *harness* sistem perlindungan anak ISOFIX dan akselerasi dada penumpang anak-anak pada tabrakan depan, dan menganalisis potensi risiko yang ditimbulkan oleh gaya tarik *harness*. Sangat penting untuk memverifikasi dan memvalidasi efek ketegangan *harness* pada potensi cedera penumpang anak-anak karena secara umum manual pengguna dan instruksi sistem perlindungan anak tidak menunjukkan sejauh mana sabuk penyetel harus ditarik, sehingga memungkinkan untuk menyebabkan kekuatan tarik *harness* untuk diterapkan semaunya. Oleh karena itu, diharapkan kesadaran masyarakat akan isu tersebut dapat ditingkatkan. Skema pengujian dirancang dan dilakukan untuk mengumpulkan informasi yang diperlukan tentang dummy P1.5 dalam tabrakan depan. Gaya tarik yang diterapkan pada sabuk penyetel ditetapkan pada 3 tingkat berbeda. Akselerasi dada diperoleh dan dibandingkan untuk menganalisis efek ketegangan *harness*. Berdasarkan hasil pengujian, hubungan antara keduanya dipastikan dan divalidasi. Selain itu, penelitian ini memberikan beberapa usulan tentang penyesuaian tegangan *harness*, dan penggunaan yang tepat dari sistem perlindungan anak ISOFIX.

Keywords: tension, acceleration, child occupant, frontal collision, safety

1. Introduction

Child restraint system is a device that can accommodate a child occupant in a sitting or supine position; the design of this system aims to diminish the risk of injury to the wearer in the event of a collision or of abrupt deceleration of the vehicle by limiting the mobility of the child's body [1,2]. The relevant installation method mainly involves the use of seat belt or ISOFIX. ISOFIX is a system that provides a method of connecting a child restraint system to a vehicle. This method is based on two vehicle anchorages and two corresponding attachments on the child restraint system in conjunction with a means to limit the pitch rotation of the child restraint system. Anti-rotation device, which is one of the core components of ISOFIX child restraint systems, is used as the device intended to limit the rotation of the aforementioned system during vehicle impact and generally comprises a top-tether strap or a support leg. ISOFIX attachments and anti-rotation devices are essential for the secure installation of ISOFIX child restraint systems. The ISOFIX child restraint system has become increasingly popular with the parents or caregivers of child occupants. Moreover, ISOFIX has many advantages that are not found in child restraint systems that use seat belt for installation; these advantages can be observed in many aspects, such as convenience, safety performance, and even comfort.

In the field of passive safety, the ISOFIX child restraint system plays an import role in protecting child occupants from preventable injuries or fatalities in road traffic accidents [3]. On the one hand, child occupants are remarkably sensitive to abrupt acceleration or deceleration and secondary impacts. Unlike adults, child occupants need extra protection when an accident occurs because it takes additional time for children to react to unforeseen emergencies [4]. Moreover, young children, such as infants, are unaware of the potential dangers of traffic accidents. Thus, a lack of necessary protective measures may result in disastrous consequences [5]. On the other hand, seat belts and many other devices relevant to passive safety cannot provide sufficient protection because they are unsuitable for young children to use. Instead, of acting as a safeguard against traffic injuries and fatalities, these devices may cause even more severe injuries when used inappropriately by child occupants [6]. However, child restraint systems could still be regarded as a perfect solution to ensuring the safety of child occupants in collisions.

The product has been standardized in many countries. Particularly, many regulations and technical standards are available for the development, manufacture, sale, and application of child restraint systems; for example, UN Regulation No. 44, UN Regulation No. 129, FMVSS 213, CMVSS 213, GB 27887-2011, and AIS-072, which have been implemented in Europe, North America, China, and India [7,8]. Meanwhile, similar standards also exist in many other countries, such as Japan, Brazil, Australia, New Zealand, and South Africa [9,10]. The standards have similarities in test items, requirements, and methods. GB 27887-2011 and AIS-072 have mainly evolved on the basis of UN Regulation No. 44. Nevertheless, the regulations in Europe also undergo adjustments and revisions. From 1st September 2020, no new approvals shall be granted under UN Regulation No. 44 to child restraint systems other than Group 3; from 1st September 2022, no extensions shall be granted under this Regulation to child restraint systems other than Group 3. Therefore, an increasing number of approvals will be granted under UN Regulation No. 129, which focuses on enhanced child restraint system, that is, the ISOFIX child restraint system [11]. Undoubtedly, the installation method using ISOFIX will overshadow that using seat belt in safety performance and the application to a remarkable extent. Hence, only the ISOFIX child restraint system was involved and investigated in the current research.

Many kinds of child restraint systems, such as infant carrier, child safety chair, carry cot, and booster cushion, are available. Certain child restraint systems are generally suitable for a specified child occupant whose weight and height fall into certain ranges. Choosing the proper child restraint system is of considerable importance to reduce or avoid injuries in accidents. ISOFIX child safety chair with support leg, which generally belongs to group 0+ and/or group I, is suitable for child occupants from newborn to 3 years old to use. The aforementioned type of ISOFIX child restraint systems are common and widely used in many places. The samples tested in the current research are child safety chairs that belong to group 0+. The weights of the occupants fall into the mass range from 3.4 kg to 11 kg accordingly. Therefore, the P1.5 dummy or the dummy of the same weight could be employed to substitute the occupant in dynamic tests.

Previous studies mainly focused on the optimization in the structural design, evaluation of injuries of child occupants in collisions, and generation of deceleration pulses of child restraint systems [12,13]. Studies on misuse and inappropriate installations were also conducted in the past, but the extent to which the harness should be tightened was seldom involved [14,15]. In addition, the user manual and instructions provide minimal information regarding the tensile force control of harness webbings. Hence, many parents or caregivers of child occupants have minimal knowledge of the proper adjustment of the harness and the influence of harness tension on the safety performance [16]. Heavy lessons of traffic accidents indicate that the relationship between safety and comfort is a paradox for child occupants [17]. A test scheme comprising six dynamic tests was devised in the research to verify and validate the aforementioned relation. The harness tension has considerable effects on the chest accelerations of occupants. Thus, the requirements of most regulations and technical standards include the following: the resultant chest acceleration shall not exceed 55 g except during periods whose sum does not exceed 3 ms; the vertical component of the acceleration from the abdomen toward the head shall not exceed 30 g except during periods whose sum does not exceed 3 ms in sled tests; therefore, the resultant and vertical chest accelerations can be perceived as the criteria for the assessment [18]. In many other fields, adjusting relevant factors may lead to the improvement of product quality and overall performance; based on the current research findings, additional research can be conducted to increase the safety of ISOFIX child restraint systems, including but not limited to optimizing the structure, avoiding misuses and inappropriate installations, and improving public awareness [19,20].

The current research focused on demonstrating the influence of pulling on forces chest accelerations because only a few similar studies have been conducted before. Instead of ascertaining some constant values of the forces, the main aim is to attract sufficient attention and increase the awareness of caregivers of child occupants regarding the safety of children in using restraint systems. Notably, safety is presented by low acceleration and comfort is presented by low tensile force to pull the adjusting belt. To ensure safety first and improve public awareness regarding using child restraint systems appropriately in a feasible way, a compromise between safety and comfort must be reached as shown in the current research, that is, the harness cannot be released completely; however, the feeling of comfort is the most evident in the situation. Therefore, the force specified in technical standards or regulations is taken as the criterion. Thus, proper adjustments of the pulling forces could easily lead to different but regular results. Structure, hardness, stiffness, and many other features of child restraint systems considerably vary, which will inevitably influence the feeling of comfort and safety. Hence, the force exerted on child occupants is not necessarily the same despite the identical forces to pull the adjusting belt. Overall, the tendency curve is applicable and shows a universal phenomenon, while the optimum force to restrain the child occupant is only applicable to one kind of child restraint system. According to the findings in the research, loosening the harness for child occupants arbitrarily is not recommended. Moreover, safety should not be sacrificed for comfort.

2. Methods

Test preparation and test scheme. Sled tests remain the most important way to reproduce real crash conditions, simulate road traffic accidents, and obtain necessary data relevant with injury criteria of a dummy [21,22]. The sled can generally be classified into the following two types: acceleration and deceleration. The sled of acceleration type surpasses that of deceleration in many aspects, such as operational convenience, accuracy, repeatability, efficiency, and flexibility in generating test pulses. However, using the latter is a cheap means for conducting dynamic tests. The sled of the acceleration type was employed in the current research to serve as the test platform, which can generate qualified acceleration and velocity pulses for child restraint systems. Test pulses are directly related to test conditions; therefore, the repeatability should be ensured if deviations are introduced to the test results. Hence, similarity and coincidence are prerequisite between real pulses and the curves that have been set as objects. The acceleration of the sled was collected by its mounted accelerometer, and the velocity was obtained by the time integration of acceleration. Curves defined in most regulations and standards could be used for reference. Relevant original frontal impact curve specified in UN Regulation No. 44 was adopted in the research; this curve is the same as the frontal impact curves specified in UN Regulation No. 129, GB 27887-2011, and AIS-072.

P1.5 dummy weighs approximately 11 kg, which is the perfect substitute for a child occupant aged 18 months. The dimensions and mass distributions of the dummy represent those of 50th percentile children aged 18 months. The dummy and the child of its age are almost of the same weight and height, thus increasing the reliability and objectivity of the test results. Moreover, only data regarding chest accelerations shall be collected; thus, using Q1.5 dummy in dynamic tests is no longer necessary. The dummy had been calibrated before the tests. The procedure of putting P1.5 dummy into a child restraint system was also controlled strictly, and every step was executed similarly for six dynamic tests. All the possible factors relevant to the dummy were considered, and the measures were taken to exclude external disturbance and prevent potential changes in test conditions.

Furthermore, a force gage was utilized for the adjustment of harness tensile force. The on-site operator pulled the adjusting belt of the child restraint system using the gage once the dummy had been put into the system, thus tightening the harness and inducing adequate tension. The force applied by the gage to the adjusting belt is directly related to the harness tension, and a large pulling force will lead to a high tension of the harness. Therefore, different levels of pulling forces can be compared on the extent to which they influence the chest accelerations.

The samples are all of the same type and category and belong to group 0+, that is, they are the same in every aspect. One sample was verified in one test and was replaced with another sample in the next test. Six ISOFIX child restraint systems were used to conduct the dynamic tests. Moreover, these systems were fit for children aged from newborn to 18 months to use. Therefore, P1.5 dummy could be put into the samples without mismatches because the space in each sample was neither redundant nor deficient. Additionally, the samples were all bought from the local market and had passed China Compulsory Certification. Thus, all the ISOFIX child restraint systems were qualified products.

The acceleration sled, P1.5 dummy, and other auxiliary instruments, such as the force gage, together with the fixture, high-speed camera, and illumination system, constitute the comprehensive test platform for dynamic tests, wherein every part is essential. Based on the test platform, a test scheme was devised to ascertain the relation between the harness tension of ISOFIX child restraint systems and the chest acceleration of child occupants. This scheme includes six dynamic tests, as presented in Table 1. Forces to pull the adjusting belt

Table 1. Test Scheme

Test No.	Forces to Pull Adjusting Belt (N)	Parameters to Measure (g)
1	150	aR: Resultant chest acceleration & aV: Vertical component of the acceleration from the abdomen toward the head
2	150	
3	250	
4	250	
5	350	
6	350	

are 150, 250, and 350 N, representing three different comfort levels, namely comfort of high level, comfort of medium level, and comfort of low level, respectively.

Experimental procedure standardization and evaluation criteria. First, the ISOFIX child restraint system was placed on the test seat. The test seat is a standard seat installed on the sled, representing the real automobile seat in a vehicle. Employing a test seat aims to ensure the standardization of initial conditions of the test relevant with the seat. The P1.5 dummy was then placed into the sample, and a gap existed between the rear of the dummy and the restraint. A hinged board 2.5 cm thick, 6 cm wide, and of length equal to the shoulder height less the hip center height in the sitting position of P1.5 dummy was placed between the dummy and the back of the child restraint. The board followed the curvature of the child restraint system as closely as possible and its lower end was at the hip joint height of the dummy. The hinged board was used to induce the slack, which is inevitable in the actual state when a child restraint system is used to protect the child occupant in a vehicle. This board is also a means of ensuring standardization of test conditions. Finally, the adjusting belt was pulled via the force gage according to the test scheme shown in Table 1. The tensions were applied at three different levels, with deflection angles of the belt at the adjuster of 45° ± 5° for all the six samples. The repeatability of the application process of the pulling force can only be ensured via the aforementioned approach. The strict execution of the test scheme is crucial to the control of harness tensile force, which is directly related to the pulling force applied to the adjusting belt.

In the installation of the ISOFIX child restraint system equipped with support leg to the test seat, the support leg as the anti-rotation device would effectively prevent the restraint from rotating in frontal collisions. To a considerable extent, the samples equipped with ISOFIX attachments depended on the support legs to remain stable in tests. During installation, ISOFIX attachments were connected and operated uniformly to ensure that the installation method would not excessively affect the test results. After all the essential installations, the hinged board was removed only before the sled system was launched and the test started. Standardization of installation is of considerable importance for the reliability, repeatability, and objectivity of test results because non-standardization will inevitably introduce additional errors and yield incomparable test results. In the research, effective measures have been taken to address the problem and ensure the standardization of experimental procedures.

Furthermore, the foam test cushion would compress after installation of the ISOFIX child restraint system; thus, each dynamic test in the test scheme was conducted no more than 10 min after installation. The period between two dynamic tests using the same cushion was set as 20 min to allow the cushion to recover. Figure 1 displays the final state of the sled and the installed ISOFIX child restraint system with P1.5 dummy in it before the test starts.

Additionally, P1.5 dummy can cause more severe damages to the restraint than the dummies of lower weight, such as P0 and P3/4 dummies in a dynamic test. One significant factor is that the object with a large mass has a large inertia correspondingly, thus generating a large kinetic energy when the velocity is certain in a dynamic test. Moreover, P1.5 dummy will face additional potential risks. Therefore, the safety performance evaluation of the ISOFIX child restraint is conducted through research on the potential injuries of P1.5 dummy. Chest acceleration is the most relevant parameter that can directly be affected by harness tension and can easily be measured by proper sensors. Thus, the resultant and vertical chest accelerations are taken as the criteria for injury assessment. In many technical regulations and standards, the two aforementioned types of accelerations are also involved and required to acquire in a dynamic test as the raw data. The data acquisition and analysis provide an effective and quantitative solution to the safety performance evaluation of samples. The resultant chest acceleration is generally not allowed to exceed 55 g except during

Figure 1. Final State of the Sled and the Sample before Test Starts

periods whose sum does not exceed 3 ms. Meanwhile, for the vertical component of the acceleration from the abdomen toward the head, exceeding 30 g during periods whose sum exceeds 3 ms should be perceived as unqualified, which will pose severe risks. All the tests were conducted employing the acceleration sled based on the experimental procedure and its standardization. All the test results were collected and analyzed un accordance with the evaluation criteria.

3. Results and Discussion

After strictly conducting the test scheme, the accelerations and velocities of the sled were collected, thus generating the test pulses, as shown in Figures 2 and 3. The figures reveal that all the acceleration pulses fall into the zone specified in most regulations and standards. They are qualified and valid pulses that meet the requirements, with the same trends as the object curves. Furthermore, the maximum velocity is 51.5 km/h and the minimum is 50.3 km/h; that is, all the velocities are valid and within the proper range. Detailed information is tabulated in Table 2, and the data regarding the velocities and accelerations of sleds are presented. Discrepancies between data exist, but the test conditions of the six dynamic tests are the same due to high coincidence between pulses.

According to the test scheme shown in Table 1, the resultant chest acceleration and vertical component of the acceleration from the abdomen toward the head were acquired in each test. Necessary data acquisition was executed through the accelerometer, the relevant data acquisition system, and follow-up data processing, thus making it possible to display pulses of resultant and vertical chest accelerations of P1.5 dummy, as shown in Figures 4 and 5, respectively. As the functions of time, the resultant and vertical chest accelerations of P1.5 dummy change in real time under the action of sled motion. For the measuring procedures, relevant specifications in ISO 6487: 2002 were considered and adopted to standardize the process of data acquisition and analysis, and the channel frequency class (CFC) was set as CFC 180 for signal filtration. Figures 4 and 5 respectively display the changes in resultant and vertical chest accelerations of P1.5 dummy with those of external factors; among which, the acceleration of the sled is significant when ISOFIX child restraint systems undergo the frontal impact dynamic tests. All the tests from No.1 to No.6 are relevant to the safety performance of ISOFIX child restraint systems with a support leg as the anti-rotation device, reflecting information in many aspects. Particularly, different test conditions regarding the harness tension of child restraints lead to varying test results despite the almost same accelerations and velocities of the sled. A relation between harness tension and the chest acceleration of the dummy undoubtedly exists in a test. How the tension affects the acceleration, and the extent to which the pulling force should be applied to the adjusting belt deserve further research. As presented in Table 3, the maximum chest accelerations of P1.5 dummy during periods whose sum exceeds 3 ms in dynamic tests from No.1 to No.6 were all obtained. The results include the resultant chest acceleration and the vertical component of the acceleration from the abdomen toward the head according to the test scheme. The relation between the harness tension of the ISOFIX child restraint system and the chest accelerations of child occupants in frontal collisions could be ascertained on the basis of data analysis.

Considering the relation between harness tension and chest acceleration as revealed in Tables 1 and 3, noticing the potential risks that child occupants suffer from in collisions is necessary for caregivers. Figures 6 and 7 emphasizes the negative correlation between them, revealing that a large harness tensile force leads to a low chest acceleration. This phenomenon is the same for resultant and vertical chest accelerations. However, controlling the harness tensile force of an ISOFIX child restraint system is a paradox because increasing the harness tension will inevitably affect the feeling of comfort, thus contributing to the unwillingness of child occupants to wear the harness or use the child restraint

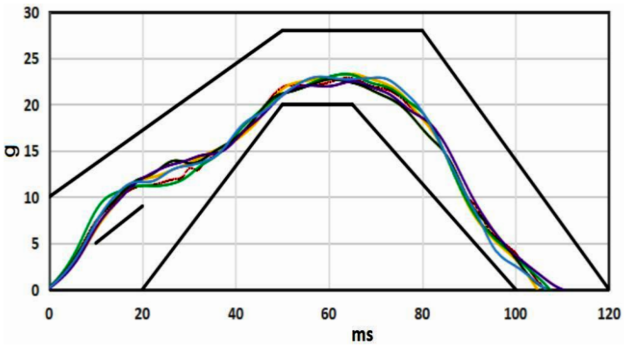

Figure 2. Sled's Acceleration Pulses in Six Dynamic Tests

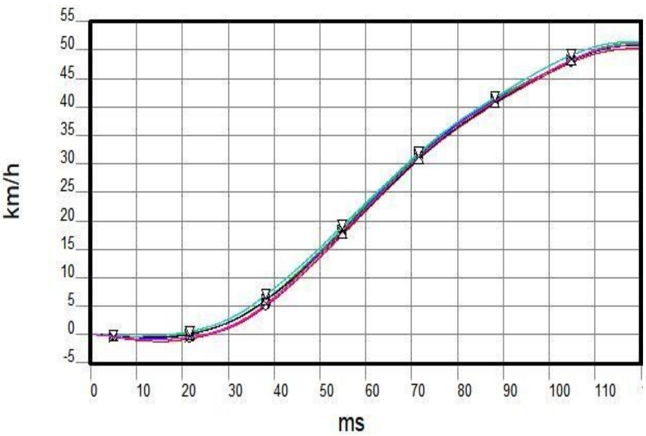

Figure 3. Sled's Velocity Pulses in Six Dynamic Tests

Table 2. Test Conditions Relevant to Sled

Test No.	Sled's Velocity (km/h)	Acceleration Pulse Compliance
1	50.8	Yes
2	50.3	Yes
3	51.3	Yes
4	50.9	Yes
5	51.5	Yes
6	50.9	Yes

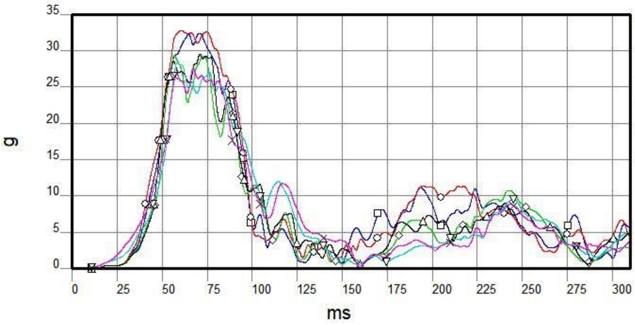

Figure 4. Comparison between P1.5 Dummy's Resultant Chest Accelerations in Six Dynamic Tests

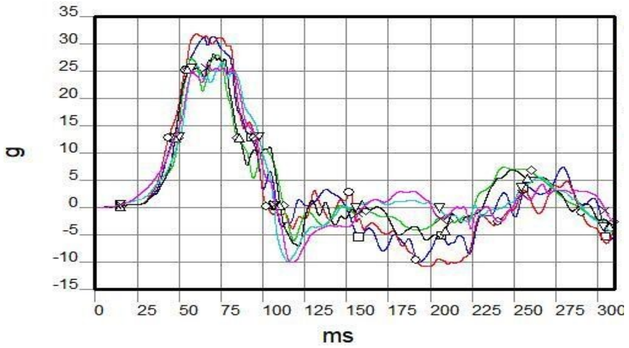

Figure 5. Comparison between P1.5 Dummy's Vertical Chest Accelerations in Six Dynamic Tests

Table 3. Test Results (Peak Acceleration)

Test No.	Resultant Chest Acceleration (g)	Vertical Chest Acceleration (g)
1	32.4	31.3
2	32.8	31.8
3	29.4	28.0
4	29.6	28.3
5	28.3	26.7
6	27.6	26.3

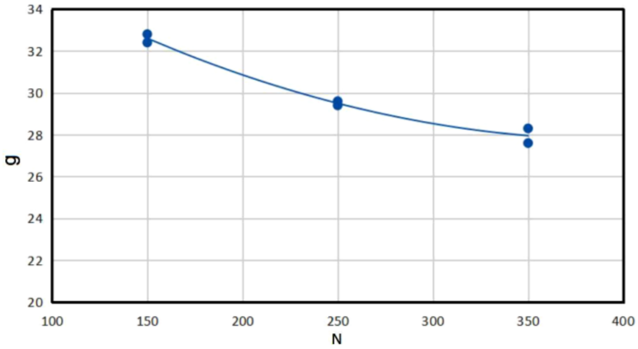

Figure 6. Relationship between Resultant Chest Accelerations and Harness Tensions

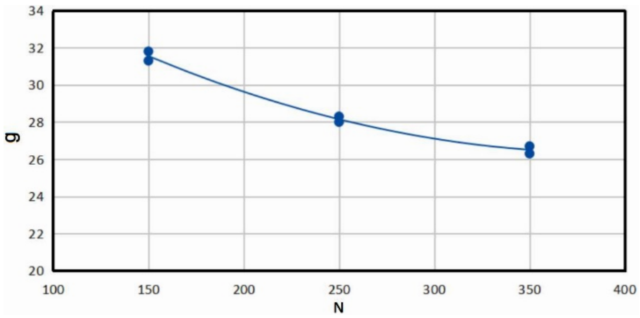

Figure 7. Relationship between Vertical Chest Accelerations and Harness Tensions

system. Nonetheless, excessively unfastening or loosening the harness while driving is dangerous because the feeling of comfort cannot be realized at the expense of safety. Overall, balance between comfort and safety is crucial.

Crash tests or simulations prove to be remarkably useful in the validation and verification of the issue. Similar methodologies could generally lead to different results even if test conditions appear identical in most aspects while a certain factor is adjusted. The effect relevant to a certain factor, that is, the pulling force to adjust the belt, is concluded and visually displayed on the basis of the test results in the scheme. However, the findings regarding the relationship between the chest acceleration of child occupants and harness tension only represent the tendency of safety under gradually changing comfort. Considering different systems and actual use, the tendency may be different to some extent because child restraint systems, child occupants, and the utilized vehicle are not necessarily the same. Value of the force varies considering same feelings of comfort of different child occupants. For example, some children are fat and tall while others are thin and short; thus, their cognition regarding comfort must be different despite identical harness tensions. Therefore, calculating or estimating the optimum value of force is unnecessary, and the optimum force is inapplicable to child restraints of other models, groups, or classes. Nevertheless, exploring the relation between chest acceleration and harness tension and ascertaining the tendency, especially for the tendency curves generated in accordance with the dynamic test results, which are representative and applicable, is remarkably meaningful. In other words, the tendency curve indicates the actual relation between safety and comfort, which is reflected in the chest accelerations of child occupants and harness tensions, respectively. Moreover, the two factors have limits: unlimited increase or decrease in the values of chest accelerations or pulling forces to adjust the belt is impossible. Safety always comes first, and neglecting or ignoring the proper exertion of pulling forces of the adjusting belt will result in injuries, damages, or even deaths at numerous times..

4. Conclusions

The test scheme incorporating six dynamic tests revealed that acceleration sled was employed to conduct the tests and simulate the frontal impact collisions. All the necessary data obtained from the tests include sled's acceleration pulses, velocity pulses, and the resultant and vertical chest accelerations of the P1.5 dummy. Accelerations and velocities of the sled constitute the fundamental conditions of dynamic tests, and their variations can also mean certain changes in sled test conditions. Test conditions determine results to a considerable extent considering sled tests that simulate real crashes. The findings and analysis lead to the following conclusions based on the comparison between test results.

A negative correlation is observed between the harness tension of ISOFIX child restraint systems and the chest acceleration of child occupants in frontal collisions. Therefore, controlling the magnitudes of harness tensile forces of restraints is important: large tensile forces of the harness generally indicate low chest accelerations during collisions. Chest accelerations are directly relevant to potential injuries. Occasionally, attention is provided to the feelings of comfort of child occupants. The feeling of comfort of occupants should be emphasized. However, the safety is of high importance and cannot be ignored, especially in the abrupt changes in vehicle accelerations that can introduce various risks. Instead, equal emphasis should be put on pulling the adjusting belt properly and fastening the harness when an ISOFIX child restraint system is used to safeguard the child against severe injuries and fatalities.

Furthermore, public awareness should be improved. The relation between the harness tension of the ISOFIX child restraint system and the chest acceleration of a child occupant as an objective existence will undoubtedly influence the safety of child occupants. Maintaining balance between safety and comfort relevant with the restraint is also necessary. Based on the research, further studies can be conducted to explore the means of adjusting the harness tensile force, the structural optimization of the child restraint system, and the amendment of user manual and instruction of restraints.

Acknowledgments

Not applicable.

References

[1] G. Lee, C.N. Pope, A. Nwosu, L.B. McKenzie, M. Zhu, J. Saf. Res. 70 (2019) 33.
[2] M. Cornelissen, M. Hermans, L. Tuijl, M. Versteeg, E. van Beeck, E. Kemler, Traffic Inj. Prev. 22 (2021) 634.
[3] R.K. Myers, L. Lombardi, M.R. Pfeiffer, M.R. Zonfrillo, A.E. Curry, Traffic Inj. Prev. 1 (2020).
[4] C. Buderer, S. Hefti, E. Fux, T. Pérez, C.C. Swenson, U. Fürstenau, B. Rhiner, M. Schmid, Child. Youth Serv. Rev. 119 (2020) 105626.
[5] Skjerven-Martinsen, P.A. Naess, T.B. Hansen, T. Staff, A. Stray-Pedersen, Accid. Anal. Prev. 59 (2013) 479.
[6] S.L. Bachman, G.A. Salzman, R.V. Burke, H. Arbogast, P. Ruiz, J.S. Upperman, J. Saf. Res. 56 (2016) 17.
[7] P. Baranowski, K. Damaziak, L. Mazurkiewicz, J. Malachowski, A. Muszynski, D. Vangi, Traffic Inj. Prev. 19 (2018) 256.
[8] B.A. West, M.A. Yellman, R.A. Rudd, J. Saf. Res. 79 (2021) 110.
[9] A. Chaudhry, I. Sanaullah, B.Z. Malik, A.A. Klair, J. Trans. Health 13 (2019) 247.
[10] D.S. Usami, L. Persia, V. Sgarra, Trans. Res. Procedia 45 (2020) 143.
[11] C. Visvikis, C. Thurn, M. Kettner, T. Müller, Traffic Inj. Prev. 21 (2020) S173.
[12] B. Albanese, K. Bohman, L. Bilston, S. Koppel, J. L. Charlton, J. Olivier, L. Keay, J. Brown, Saf. Sci. 128 (2020) 104707.
[13] Y. Liu, X. Wan, W. Xu, L. Shi, G. Deng, Z. Bai, Accid. Anal. Prev. 164 (2022) 106476.
[14] S. Levi, H. Lee, W. Ren, S. McCloskey, A. Polson, Traffic Inj. Prev. 21 (2020) 453.
[15] P.D. Tremoulet, A. Belwadi, B. Corr, S. Sarfare, T. Seacrist, S. Tushak, Trans. Res. Interdiscip. Perspect. 10 (2021) 100372.
[16] F.M. Butt, M.A. Dalhat, K.S. Minhas, A. Al-mojil, J. King Saud Univ. Eng. Sci. (2021).
[17] S. Kendi, M.B. Howard, M.A. Mohamed, S. Eaddy, J.M. Chamberlain, Traffic Inj. Prev. 22 (2021) 224.
[18] A.V. Ngo, J. Becker, D. Thirunavukkarasu, P. Urban, S. Koetniyom, J. Carmai, J. Saf. Res. 79 (2021) 26.

[19] M. Hajsadeghi, M. Jalali, C.S. Chin, T. Zirakian, M. Bahrebar, Int. J. Eng. Trans. C Asp. 34/6 (2021) 1390.
[20] H. Hosseinnejad, M. A. Lotfollahi-Yaghin, Y. Hosseinzadeh, A. Maleki, Int. J. Eng. Trans. A Bas. 34/04 (2021) 782.
[21] C.S. Parenteau, D.C. Viano, R. Burnett, Traffic Inj. Prev. 22 (2021) 43.
[22] Z. Wei, Int. J. Eng. Trans. C Asp. 34/12 (2021) 2658.