ANALYSIS OF CHILDREN STROLLERS AND PRAMS SAFETY IN URBAN BUSES

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ABSTRACT

The wide incorporation of low floor buses in our cities encourages that child younger than three years, seated on their stroller could use the buses. Currently, the UNECE Regulation No 107 at its revision 5 has included general provisions for the accessibility and basic safety for this type of users. An applied research has been performed to analyze the level of protection offered for the stroller restraint systems included in R107, by performing dynamic tests with instrumented dummies.
More than 20 dynamic sled tests were performed to assess the child safety in urban buses. Two types of configurations have been tested: a vehicle specific CRS for urban buses and the own stroller with different restraint systems.
The specific vehicle built-in CRS tested is a rearward facing group 0/I that is currently in use in the city of Madrid (Spain) by the public urban buses. This CRS was tested in frontal and rear impact with the acceleration pulse defined in the UNECE regulation No 80.
On the other hand, to make suggestions for using the stroller in urban buses, a very low severity crash pulse (up to 2 g peak acceleration and ΔV = 20 km/h) was defined and used in this study. Four stroller models with three types of restraint devices (safety belt, PRM wheelchair backrest and a folding backrest device) were tested with this pulse. The strollers were selected in order to reduce biasing of the results.
Several dummies (P3, Q3 and Q1) were used to evaluate the injuries and the kinematics. Furthermore, different sources of IRAV have been applied for the Q dummies (R94 and FMVSS 208 scaled by applying Mertz 2003 techniques), an extended range of injury criteria is obtained and an in depth analysis of the protection offered by the different restraints systems used is performed.

INTRODUCTION

The use of public transport is a need and a right for all citizens. However, there are still some groups who experience difficulty travelling on buses – such as users who travel with pushchairs or strollers. These users also face safety problems as it is often necessary for children to be taken out of their strollers and held in the arms of their accompanying person. From the standpoint of operating companies, the use of buses by this group represents a design problem that has not yet been satisfactorily and effectively resolved at the moment of perform this research study.

One of the studies published regarding the use of buses by passenger travelling with pushchair [1], analyze the response of a survey applied to 44 Spanish transport companies (69% of the total). The results show that 32% of bus companies use local legislation to regulate the access to buses by pushchair users, 27% applies internal regulations, 11% respond to regional legislation, and up to 30% of companies do not apply any regulations. Of all the companies surveyed, 45% allow pushchairs to be open inside the bus, while 32% prohibit pushchairs from being open. Most companies (41%) have not defined the number of pushchairs allowed on a bus, while 34% allow access for up to two pushchairs, and 25% allow only a single pushchair. Note that priority is given to wheelchair users over pushchairs by 23% of these companies, while the remainder (77%) does not specify priority. Access for pushchairs is usually (preferably) through the front door, although central door entry is allowed (even without using the ramp), while exiting is normally made through the central or rear doors.

Pushchairs are usually positioned parallel to the longitudinal axis of the vehicle and facing backwards. Some 25% of bus companies require that the pushchair brake is applied to the wheels during transport (as the pushchair is open), while no indication is provided by the remaining 75%. Finally, only 18% of the companies surveyed explicitly deny access to tandem (twin) pushchairs.

Recently, at June 2014, the UNECE regulations (United Nations Economic Commission for Europe) in its regulation 107R05 (current version of the regulation 107 is R06 from March 2015), has modified the accessibility requirements of Class I vehicles (urban buses), extending the previous requirement of at least one wheelchair user to also at least one pram or unfolded pushchair at same time.

The work reported in this paper is focus on the child safety (children under 3 years old) in urban buses. Children under 3 usually used Child Restraint System – CRS (approved under regulation 44 or in future the i-Size category according regulation 129). Nevertheless in urban buses this type of CRS could not be used (technically because there is no safety belt or ISOFIX installed in urban buses seats; and it is not practical for the user that must wear their own CRS for buses). There are clearly two tendencies: on one hand to use a specific built-in child restraint system (with national or regional approval) and on the other hand to establish prescriptions for use the strollers or prams inside the urban buses in order to obtain a certain level of safety (the same direction than regulation 107), however R107 does not require any dynamic evaluation of the restraint system included into vehicles.

To bring some information to the previous mentioned options, dynamic sled tests have been performed in order to assess the safety behaviour in urban buses with different safety devices, and oriented to achieve the following objectives:

- Know the accelerations of a specific built-in child restraint system for urban buses tested with the acceleration profile as defined in the regulation 80 (for coaches). The safety assessment is evaluated objectively in order to obtain the accelerations levels as a maximum in order that this level could be useful to establish a reference for the child safety evaluation in urban buses.
- Evaluation of the child safety behaviour in urban buses using strollers or prams. In this case, it has been developed a low severity pulse in order to assess this behaviour.
- Analyze the safety of different systems (safety belt, PRM backrest or a prototype [2] of folding backrest), using different types of strollers. It is not the objective of the study to evaluate if one stroller is better or worse than others.

METHODS

Two severity pulses are used in this study. For the strollers, several frontal low severity impact sled tests were performed in order to assess the safety performance of different strollers restrained with different systems to the urban bus (a PRM backrest, a folding backrest and a 2P stroller safety belt). Furthermore, for the specific built-in CRS, three sled tests (2 frontals and 1 rear) were performed with the acceleration profile defined in regulation 80R03, more severe than previous ones. The next figure shows the differences of the two severity pulses carried out (these pulses are obtained from real sled test deceleration). The low severity pulses represents conditions more severe than the emergency manoeuvres (limited by the friction coefficient between the tire and the road), but there is not intended to replicate a bus crash, therefore the acceleration should be greater than 1 g. An increase of 50% was imposed (i.e. an acceleration of at least 1.5 g). The duration of the dynamic impact was limited by the capabilities of the sled facility used, with a maximum stroke of 1200 mm. Finally it was established a ΔV = 20 km/h (compatible with the total braking distance available).

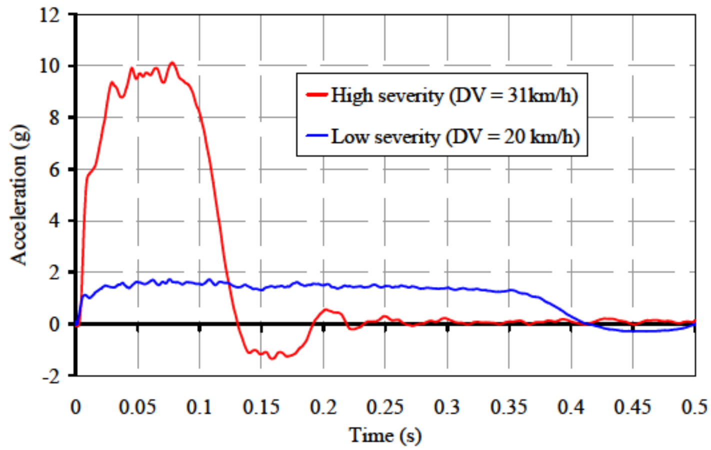

Figure 1. Sled acceleration for the two severities.

Four types of occupants were used to perform the dynamic sled tests:

- Ballasted mannequin of 9MO: with a total mass of 9 kg. Used to assess the kinematics response.
- Q1 dummy. The measurement capabilities used in tests are: head acceleration (X, Y, Z), upper neck forces (X, Y, Z), upper neck moments (X, Y, Z), chest acceleration (X, Y, Z), chest deflection and pelvis acceleration (X, Y, Z).
- P3 dummy with head acceleration (X, Y, Z) and chest acceleration (X, Y, Z).
- Q3 dummy with chest acceleration (X, Y, Z).

Furthermore to the dummy measuring capabilities, two or three high speed cameras (1000 fps) were used to evaluate the impact kinematics of the dummies and the strollers. The next figure shows a sketch of the sled test with the views of the two high speed cameras (the third camera is a zenithal view). As it can be seen, a representative urban bus floor was installed on the sled. This floor includes the PRM backrest, the folding backrest and the 2P stroller safety belt.

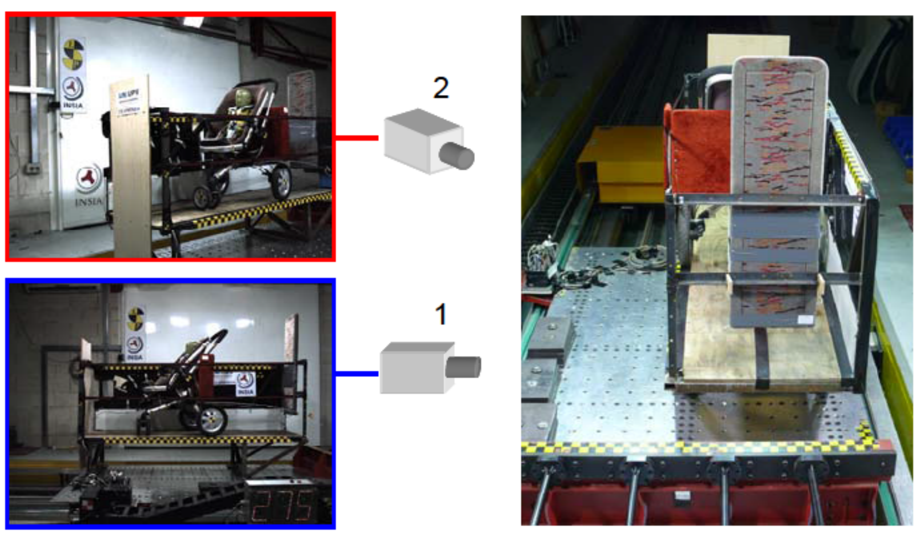

Figure 2. High speed cameras and test ring set up.

The dynamic sled tests were performed in two phases:

- **Phase1**: High severity dynamic tests (according regulation 80R03) with a specific built-in rearward facing child restraint system. The objective of this phase is to obtain the safety performance of a specific child restraint system built in an urban bus.

- **Phase2**: Low severity dynamic tests (ΔV = 20 km/h; 1.5 g) with strollers and baby carriage with different safety devices:
    - **Phase2A**. Larger number of dynamic tests with: folding backrest, PRM backrest and 2P safety belt as safety devices used to restraint the strollers. Four types of strollers have been tested in this phase. The objective of this phase is to analyze the general behaviour of the strollers and the safety devices.
    - **Phase2B**. Finally, in this latter phase a Q1 dummy (with larger measurement capabilities) was used in order to study in detail the behaviour of the strollers with the safety devices. Two types of strollers and two types of safety devices were studied.

Samples

Different samples have been tested during the dynamic tests (see Figure 3). For the dynamic tests, the strollers have been used in the configuration of the bigger child (i.e. the worst situation for the restraint and stability of the stroller is produced with the heavier child). The strollers have been selected with different configurations or features but all of them are current market representatives. The main characteristics of them are summarized:

- For the high severity pulse, a **specific built-in** (in an urban bus – **M3 vehicle category, Class I**) child restraint system was used. This CRS is rearward facing oriented and incorporates an integral 5p safety harness. This system is based on the design of the traditional CRS according regulation 44R04 for group I rearward facing oriented. The buckle and the straps fulfil the requirements of the regulation 44R04.
- **Stokke Xplory**. Incorporates a telescopic rod for height adjustment. The main characteristic of this stroller is the height of the centre of gravity that is greater than the other models. The child is restrained to the stroller using a 5p harness.
- **Quinny Buzz**. This stroller has been selected because it has 3 wheels (the frontal is twin wheel). This produced a potential instability of the stroller. The child is restrained to the stroller using a 5p harness.
- **Bebeconfort Streety**. This stroller has a large wheelbase compare with the rest of the dimensions. It was tested in a lateral configuration in order to produce more instability. The child is restrained to the stroller using a 5p harness.
- **Maclaren Quest**. It is the "traditional stroller", with four wheels (same track width front and rear). The child is restrained to the stroller using a 5p harness.

Built-in (M3-Class I)	Stokke Xplory	Quinny Buzz	Bebeconfort Streety	Maclaren Quest

Figure 3. Built-in (M3 vehicle) CRS and strollers used (figures are not to same scale).

Injury Assessment Reference Values (IARV) – extended range

The anthropomorphic tests devices (ATD) or dummies are very useful and a good measurement tool as a substitute for the human body under crashes. Thanks to their measurements capabilities is possible to establish a baseline or boundaries to determine whether there is a likelihood of injury.
The injury criteria are primarily developed for adult size dummies (specifically for the Hybrid III 50th male). The reference values for child dummies should be scaled form the data of average size adult occupant. The

injury criteria used in this paper (for the Q1 dummy) are obtained from information contained in the regulation 94R02 and FMVSS 208, scaled with the information provided by Mertz et al [3] (where it is described the scaling process for developing the IARV for different sizes and ages). Current IARV used for Q1 at R129 were not used because the pulse severity used at present study is much lower than in R129 (20 kph versus 50 or 30 kph), also and a extended set of IARV with respect to R129 is used and to avoid any collateral effects for use different sources of the IARV, a common procedure were used to obtain the set of injury criteria.

Dummy part	Parameter	Unit	Limit
Head	HIC_{15}		389.00
	HPC (HIC_{36})		555.71
	Acceleration	g	154.00
	3ms acceleartion	g	68.44
Upper neck	Shear force Fx	N	740.00
	Tension force +Fz	N	783.45
	Compression force -Fz	N	960.00
	Lateral moment Mx	Nm	21.00
	Flexion moment +My	Nm	27.00
	Extension moment -My	Nm	8.31
	Twist moment Mz	Nm	14.00
	Nij		1.00
	· FT	N	1610.00
	· FC	N	1470.00
	· MF	Nm	42.50
	· ME	Nm	18.60
	NIC		Corridor
Chest	Sternum deflection Dx	mm	24.00
	T4 acceleration	g	87.00

NOTE: All the values in the table are peak values, except the 3ms head acceleration.

Grey data are obtained based on the regulation 94R02 and scaled to Q1 dummy.

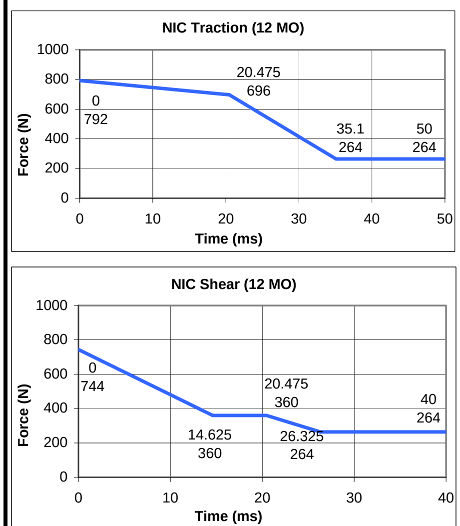

Figure 4. IARV obtained for a Q1 dummy.

RESULTS

This section summarized the results of the dynamic sled tests performed with different severities, strollers, dummies and restraint systems (as mentioned before):

- **Phase1**: High severity dynamic tests (according regulation 80R03) with a specific rearward facing child restraint system.
- **Phase2A**: Low severity dynamic tests (ΔV = 20 km/h; 1.5 g) with strollers and baby carriage with different safety devices (folding backrest, PRM backrest, safety belt).
- **Phase2B**: Low severity dynamic tests (ΔV = 20 km/h; 1.5 g) with the most unstable strollers with folding table and PRM backrest and misuse evaluation. These tests have been performed with a Q1 dummy.

Phase1 (P1)

In this phase, a Q3 instrumented dummy has been used for assess the performance of a rearward facing child restraint system built-in in a urban bus (M3 category, class I). This system was manufactured using components with the individual approval of regulation 44R04 for the group I, therefore this system may offer safety performance equivalent to the CRS used in M1 vehicles. Three tests have been performed in this phase:

- 2 rearward facing impact tests (P1-1 and P1-2).
- 1 forward facing impact test (P1-3).

The next table summarized the chest acceleration of the Q3 dummy in the tests and a picture obtained from the High Speed camera register.

Table 1. Summary results of the phase 1, (urban bus with specific vehicle CRS).

Test ref	Sled Vel (km/h)	Chest AccR 3ms (g)	Chest Vert AccZ (g)	RF (t = 100 ms)	FF (t = 100 ms)
P1-1	30.78	14.82	4.08		
P1-2	31.16	15.64	10.97		
P1-3	31.19	20.83	8.94		

Phase2A (P2A)

The second phase is focused on the assessment of the safety performance of restraint devices with the strollers in the urban bus. Initially (in phase2A) a large number of samples were tested (see Figure 3) with three types of safety devices:

- 2P safety belt (Br3 according regulation 16R08, i.e. two point belt with retractor and automatically locking retractor).
- PRM backrest installed in the urban bus
- Folding backrest (developed in ASUCAR project under P-201131557 patent [2]). It is objective of these test to evaluate this device and provide (if necessary) solution for improved it.

The next figure shows a picture of the sled with a representative section of the urban bus. This section is used for the three types of safety devices.

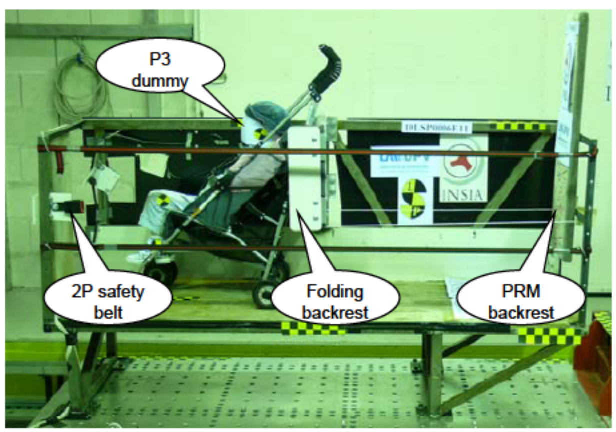

Figure 5. Urban bus module with three safety device types installed.

14 sled tests were performed with:

- P3 dummy and Ballast 9MO dummy. One tri-axial accelerometer was installed in each stroller for measure its acceleration during the dynamic tests.
- 4 types of strollers (see Figure 3).
- 3 types of safety devices (described above).
- Different configurations: rearward facing, forward facing, misuse in the belt path, break and without break the strollers' wheels, etc)

In this phase, kinematics analysis was made in order to verify the restraint of each type of the safety device. The results of these test have allow to design the test matrix for the phase2B, with has been performed with a Q1 dummy (more biofidelic dummy and instrumentation capabilities).

Phase2B (P2B)

The next table shows the test matrix of the phase2B.

Table 2. Test matrix of the phase2B.

Test ID	Stroller	Safety device	Comments
P2B-1	Stokke Xplory	Prototype #1	Stroller placed 89 mm from the first contact of the folding backrest. The stroller breaks are deactivated
P2B-2	Stokke Xplory	PRM backrest	150 mm gap between the stroller and the PRM backrest. The stroller breaks are deactivated
P2B-3	Stokke Xplory	Prototype #2	150 mm gap between the stroller and the folding backrest. The stroller breaks are deactivated
P2B-4	Quinny Buzz	Prototype #3	The stroller in contact with the backrest with the breaks activated (this is the recommended usage).
P2B-5	Quinny Buzz	Prototype #3	150 mm gap between the stroller and the folding backrest. The stroller breaks are deactivated
P2B-6	Quinny Buzz	PRM backrest	The stroller in contact with the PRM backrest with the breaks activated (this is the recommended usage).

As it can be seen, there are three types of prototype folding backrests. The three prototypes are manufactured with metal frame and covered with wooden plates. The first prototype has a total height of 500 mm, whilst the second has 400 mm. The third prototype has as well 400 mm of total height but is covered by a padded surface (similar to a carpet).
All the tests were performed with a Q1 dummy instrumented as mentioned in "**METHODS**" section, except the test P2B-1 with a P3 dummy.

The objective of test **PB2-1** was to verify the structural strength of the pushchair panel prototype#1 using the heaviest dummy (TNO type P3 weighing 15 kg). This configuration was considered as a "misuse" as it aimed to verify the behaviour of the least stable pushchair, with the tallest panel prototype, and without brakes applied to the wheels. The pushchair was placed facing backwards and in its lowest position. The free flight distance between the rear wheels and the restraint system (prototype #1) was 89 mm.
The aim of test **PB2-2** was to verify the structural strength and behaviour of a restraint for wheelchair users (PRM backrest) using the instrumented Q1 dummy (representing a one-year-old child). This configuration is considered as "misuse" as it was intended to verify the behaviour of the least stable pushchair when interacting with the panel used by wheelchair users. In this case, the stroller was configured in its highest position, with a distance from the pushchair grab-bar to the panel (in a horizontal position) of 150 mm – and without brakes applied to the wheels.
The aim of test **PB2-3** was to verify the structural strength of the prototype #2 using the Q1 instrumented dummy. These conditions represented a "misuse" because the stroller was the least stable pushchair and was positioned facing backwards in its highest position with a distance of the centre bar to the panel of 150 mm – and without brakes applied to the wheels.
Test **PB2-4** aimed to verify the structural strength of the prototype #3 using the Q1 dummy. This configuration was considered as "correct use". The stroller was located with the side bars of the pushchair touching the panel – and with brakes applied to the wheels.
Test **PB2-5** was intended to verify the structural strength of the prototype #3 using the Q1 dummy. This configuration is considered a "misuse" as it examined the behaviour of the backward facing stroller when interacting with the prototype #3 when the sidebars of pushchair were 150 mm from the panel – and without brakes applied to the wheels.
Finally, test **PB2-6** aimed to verify the structural strength and behaviour of the panel for wheelchair users (PRM backrest) using the Q1 dummy. This configuration is considered "correct use" as it verified the behaviour of the widest pushchair when interacting with the PRM backrest. In this case, the stroller was located with the handle (horizontal) touching the PRM backrest, and brakes applied to the wheels.

It should be noted that the goal of tests **PB2-2** and **PB2-6** was not only to verify the structural strength of the new pushchair restraint but to compare dynamic behaviour in settings of correct use and misuse in relation to the technical requirements defined in UNECE regulation 107.

The next table shows the results of the Q1 dummy with respect to the IARV obtained in Figure 4.

Table 3. Q1 dummy results relative to the IARV obtained.

Dummy part	Parámetro	Value (% wrt the IARV)				
		P2B-2	P2B-3	P2B-4	P2B-5	P2B-6
Head	HIC_{15}	3 5	1.2	0 3	6.1	0 2
	HPC (HIC_{36})	2 5	0.8	0 3	4.3	0 3
	Acceleration	12.6	11.8	4 2	21.6	3 5
	3ms acceleartion	27.6	21.2	9 3	40.8	7 9
Upper neck	Shear force Fx	16.4	10.0	9.7	22.8	3 2
	Tension force +Fz	11 5	10.1	2.4	17.2	3 9
	Compression force -Fz	6 2	4.5	1 0	8.0	1.4
	Lateral moment Mx	8.0	3.2	4.4	4.0	1.4
	Flexion moment +My	7 0	2.3	3 2	11.0	1.1
	Extension moment -My	**112.7**	**94.8**	**58.5**	**126.4**	44 2
	Twist moment Mz	13.7	4.9	9.4	10.6	3.6
	Nij TF (Tensile-Flexion)	5.4	2.9	2.4	8.6	0 8
	Nij TE (Tensile-Extension)	41.1	44.6	20 8	**59.9**	21 5
	Nij CF (Compression-Flexion)	5 3	2.1	0.7	5.4	1.4
	Nij CE (Compression-Extension)	**54.3**	39.3	26.4	**56.3**	10.7
	NIC Tensile	11.4	10.8	5 2	17.0	8 2
	NIC Shear	18.4	10.3	14.4	23.8	7.1
Chest	Sternum deflec ion Dx	3.4	4.4	0 5	3.1	0.1
	T4 acceleration	13.7	16.5	5 3	21.5	4 0

As it can be seen in the previous table, the extension moment has values that exceed the IARV. All the tests with "misuse" configuration have obtained values greater than 90% (and in two tests over exceed the limit). The tests performed according with the recommendations (PB2-4 & PB2-6) has been obtained values around the 50% of the limit. The rest of the parameters have not got value potentially injurious. Two comparisons in detail are made: P2B-2 vs P2B-3 and P2B-4 vs P2B-5.

P2B-2 vs P2B-3

In this case, two test configurations, classified as misuse, were compared. The least stable stroller due to its high centre of gravity was used, and in one of the tests it was supported by the PRM backrest and in the other test (P2B-3) was supported by the folding backrest (prototype #2). Figure 6 shows a superimposed image of the two configurations with the relative position of the pushchair during free flight of 150 mm towards each of the restraint systems.

Table 3 shows the results of the tests. Although the distance of free flight in both cases were the same (150 mm), the difference in height between the two panels and the contact point of the pushchair with them, produces differing behaviour in each case. Thus, while the contact of the pushchair with the PRM backrest system occurs with the back of the (horizontal) pushchair handgrip, the contact with the folding backrest (prototype #2) occurred lower down with the central telescopic rod on which the chair is mounted. Although the distance of free flight is the same, the horizontal displacement of the pushchair in the case of the PRM backrest is greater, because the handgrip bends when it comes into contact with the panel and the pushchair continues travelling until the telescopic mast strikes the panel (see Figure 7). As a consequence, all the values obtained in the test with the PRM backrest system (P2B-2) are higher than those obtained with the folding backrest (P2B-3).

The most critical parameter in both cases corresponds to neck extension moment of the dummy. The limit was exceeded by 12% in the case of the PMR backrest, while in the case of the folding backrest the values did not reach the limit of tolerance (5% below the limit).

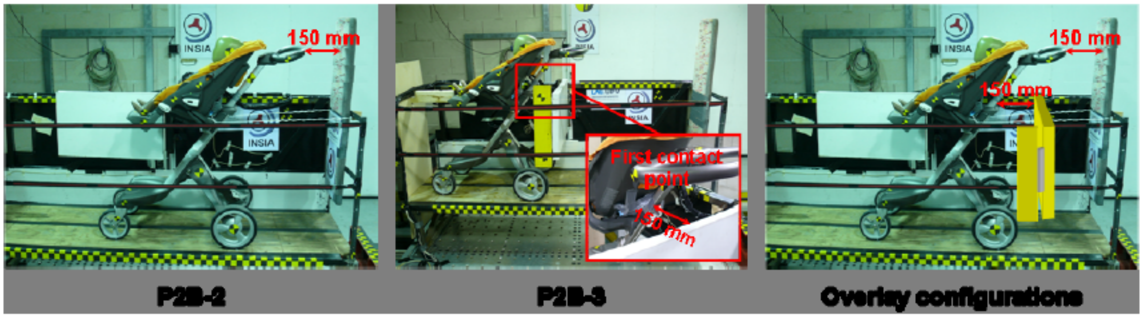

Figure 6. P2B-2 & P2B-3 configurations and a superimposed figure.

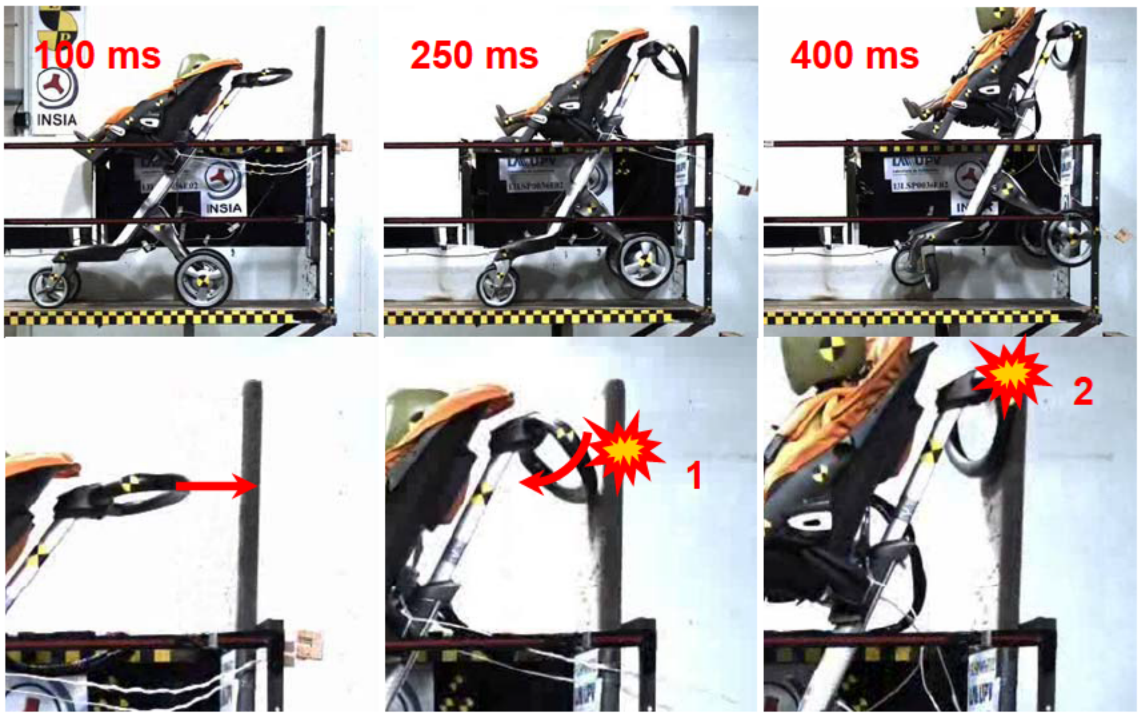

Figure 7. Kinematics analysis of the P2B-2.

P2B-4 vs P2B-5

In this case, two configurations were tested using the same stroller, one of the widest models and a model with three wheels (twin wheels for the frontal). The analysis compared a "correct" configuration (P2B-4 test) in which the stroller was in contact with the folding backrest (prototype #3) and the brakes were applied to the wheels, with a "misuse" configuration (PB2-5 test) with the PRM backrest, with a free flight distance of 150 mm and finally, the brakes were not applied to the wheels.

Table 3 shows the results of the tests, and it can be seen that all the parameters obtained for the PB2-5 test ("misuse") were worse than those obtained for the PB2-4 test ("correct use"). Only a small gap of 150 mm between the pushchair and the panel caused all the registered levels to double or more. The highest critical values exceeding the tolerance level were reached for the vertical extension of the neck, which exceeded the level of tolerated damage by 26%. Values increased by up to four times for head and chest accelerations, although critical values were not exceeded.

CONCLUSIONS

The main conclusions of the analysis of children strollers' safety in urban buses are:

- The safety belt has probed that is able to restraint the strollers and baby carriages in low severity frontal impact. Although there are potential risk configuration (the path of the belt in the strollers), it has not been able to reproduce any unstable configuration in the tests. This system is the only device that guarantees the retention of the child whatever be the impact direction.
- The folding backrest (tested in phase2B) is able to withstand the loads of the stroller occupied by one dummy (total mass 25 kg). As mentioned before, the folding backrest has being developed under patent [2].
- The misuse configuration tested in phase 2B has probed that the measurement on the dummy parts (injury readings) has grown up from 2 up to 5 times with respect to the recommended or standard situation. Therefore, it is highly recommended to follow the directions noted by usage recommendations.
- With respect to the folding backrest or the PRM backrest, neither of them have got positively restrained the stroller. In crash configuration or acceleration fields that are not longitudinal, there may be an uncontrolled movement of the stroller inside the urban bus.
- Despite the low severity tested, potentially injury situations have been reproduced.
- Currently the regulation 107R06 only provides as safety device the PRM backrest for restraint the strollers. The folding backrest (from the ASUCAR project) provides a similar solution that complements the requirements of the regulation. Furthermore, the regulation framework does not provide a solution for cases in which a wheelchair user and stroller coincide on the same journey on the urban bus. Therefore the folding backrest could be an alternative solution for transportation compatibility of different users.
- The specific built-in child restraint system has obtained four times chest acceleration with respect to the "correct use" in low severities, but the same levels with respect to the "misuse" configuration. The specific built-in CRS has been tested with a crash severity more than 6 times greater than the low severity. That means that this system is safer than the other systems (as it has been estimated).

ACKNOWLEDGEMENTS

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