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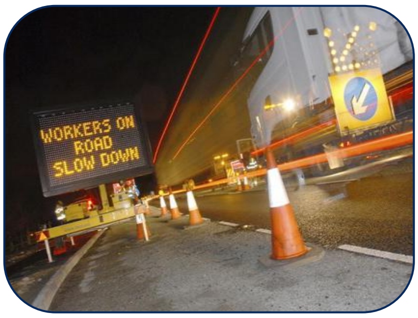

CLIENT PROJECT REPORT CPR1303

Global Impact Dummies - Assessment concerning BioRID II in Future Regulatory Applications

Final Report

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Executive Summary

UN Global Technical Regulation 7 (GTR-7) includes a dynamic test of head restraint geometry using the Hybrid III crash test dummy. GTR-7 also includes a provision for Contracting Parties (CPs) to adopt a suitable test procedure using the BioRID II rear impact dummy. The GRSP Informal Group on GTR-7 Phase 2 is now working to develop a rear impact test procedure and seat performance criteria using the BioRID II dummy that is acceptable to all CPS. The Informal Group have tasked the BioRID Technical Evaluation Group (TEG) with demonstrating the suitability of the BioRID II dummy for use in regulation and, if necessary, updating the dummy, certification procedures, user manuals and so forth to ensure that the dummy is suitable for regulation.

As a contribution to the work of the Informal Group and the TEG, the European Commission contracted TRL to evaluate the repeatability and reproducibility of BioRID II dummies that were certified to the latest build-level defined by the Informal Group. To meet this need, TRL developed a special seat rig based on a production car seat that was modified to make it more robust, and to ensure that the seat recliner response was repeatable. The goal of the seat development was to have an interface between the dummy and the seat that was as close as possible to a typical production car seat, while enabling it to be used for a large number of repeatable tests. The head restraint mounting was also revised to allow a range of backset positions.

A comprehensive testing programme was planned, using four dummies that met the Informal Group build-level and maintenance checklists, and which were certified using the latest versions of the with-head-restraint, without-head-restraint and jacket certification tests defined by the Informal Group. A first series of 20 tests was performed with a relatively large backset of approximately 75 mm, with the intention of performing a similar matrix of tests with a medium and small backset of 55 mm and 35 mm respectively.

The first series of 20 tests (baseline tests) showed that the test condition was highly repeatable, with a very repeatable pulse, a well-controlled seat back response, and minimal observed degradation of seat foams. The results showed good reproducibility for the upper torso and head accelerations, as well as for T1 X-axis shear force Fx, T1 Y-axis moment My, and upper neck X-axis shear force Fx. However, reproducibility was found to be poor for the T1 and upper neck Z-axis force Fz, and for the upper neck Y-axis moment My. It should be noted that the GTR-7 Informal Group has not yet selected injury or seat assessment criteria for use with the BioRID II dummy, so it is not known whether any of these channels would be used in the regulation. However, there was also poor reproducibility for the ramping-up behaviour of the dummy, which would be expected to affect the reproducibility of dummy measurements in general.

Following discussions with the TEG, and with the agreement of the EC Project Officer, the test matrix was revised to attempt to identify which dummy characteristics were responsible for the observed reproducibility issues, and to identify whether updates may be required to the certification procedures in order to ensure dummy reproducibility. As part of this effort, two additional dummies were provided by PDB and incorporated into the test matrix. In total, a further 39 tests were performed to investigate the source of the observed variability.

Both the pelvis and spine characteristics were found to significantly influence the dummy measurements for which poor reproducibility was observed. It was also observed that

the primary neck response in these tests was flexion, not extension. This correlates well with recent findings reported to the GTR-7 Informal Group by Japan and the USA, which found a correlation between neck flexion and injury in accident replication simulations and PMHS studies respectively.

In addition, the present certification tests may not adequately control front cervical spine bumpers characteristics, which will be important for flexion response. The certification sled test also does not include the pelvis, so cannot be used to control pelvis response, and does not substantially load the lumbar bumpers, so does not control these parts of the dummy.

A pelvis certification test had been trialled by the TEG several years ago, but was not put into routine use. This pelvis test was reintroduced in this project in order to evaluate the stiffness of the pelvis flesh of the dummies used in this programme and substantial variation in this dummy characteristic was also found.

From this work a number of recommendations have been made regarding the dummy build-level, certification tests and certification requirements. The main recommendations are:

- The stiffness of all of the spine bumpers installed in the dummy should be much more tightly controlled, e.g. by a quasi-static force-deflection test, even before a certification test is performed; the tolerance should be at least equivalent to that of the hardness tolerance specified in the drawing package
- All dummy jackets should meet the certification requirement, and consideration should be given to controlling the slope of the impactor force-time response
- All dummy pelvises should meet a new certification requirement based on the test procedure previously developed by the TEG, including control of the slope of the impactor force-time response
- The tolerance on the input parameters for the certification tests should be tightened in order to improve reproducibility
- A method for certifying the response of the front neck bumpers should be developed, because these are not as well controlled by the current certification tests as the rear bumpers
- A number of recommended changes to the certification corridors should be considered
- A smoother rear profile for the pelvis bone geometry should be implemented

It is further recommended that a number of dummies should be upgraded to meet the above recommendations, and their reproducibility re-evaluated. If this is shown to improve the reproducibility to an acceptable level for those channels that are adopted for use in the GTR, then it is also recommended to assess the bumper age-hardening effect to ensure that the current recommendation to replace front neck bumpers every four months is adequate, and to check whether a similar requirement should be introduced for the other spine bumper.

1 Introduction

UN Global Technical Regulation 7 (Head Restraints) was established on the Global Registry in 2008[1], following several years of development by the GTR-7 Informal Group under the direction of GRSP and WP.29 in Geneva. GTR-7 2008 is usually referred to as Phase 1, and includes a number of options for static tests of head restraint geometry and a dynamic test of head restraint geometry using the Hybrid III frontal impact crash test dummy. GTR-7 Phase 1 also includes a provision for Contracting Parties (CPs) to adopt a suitable test procedure using the BioRID II rear impact dummy, provided that the procedure has first been adopted in the CPs national regulations.

The GTR-7 Informal Group is now working on Phase 2, for which the ultimate goal is to develop a rear impact test procedure and seat performance criteria using the BioRID II dummy that is acceptable to all CPs. Although the BioRID II is generally reported to have good repeatability, one of the key outstanding issues with the dummy is reproducibility of tests results between different BioRID II dummies, which has been found to be insufficient for some of the parameters measured by the dummy that are used for seat performance testing. As a result, the BioRID Technical Evaluation Group (TEG), in collaboration with the dummy manufacturer, has been working to develop new certification procedures and user manuals with the aim of reducing the variation between dummies and therefore delivering acceptable reproducibility.

1.1 Project Objectives

The primary objective of this project was to assess the repeatability and reproducibility (R&R) of the BioRID II dummy that meets the latest build level and which had been evaluated against the latest assembly and maintenance checklists. It was planned to evaluate four BioRID dummies at the proposed GTR-7 Phase 2 pulse (with a delta-*v* of 17.6 $km.hr^{-1}$), with different head restraint positions that are representative of 'good', 'moderate' and 'poor' head restraint geometry.

However, the first phase of testing identified substantial reproducibility issues for three channels: T1 shear force, upper neck shear force, and upper neck My. Following discussion with the TEG and the EC Project Officer, the test programme was revised to focus on the cause of the observed variations in dummy responses, and to attempt to define improvements in the dummy build-level and certification procedures that reduce the variations to an acceptable level.

[1] www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29registry/gtr7.html

2 Method

Testing was undertaken on the acceleration sled at BASt, Cologne, Germany, using a custom-designed rear impact seat rig based on a production car seat. Detailed information on the seat, dummies, seating procedure and other aspects of the test configuration are given in the following sections.

2.1 Test Pulse

All testing used the sled pulse specified in the draft GTR-7 Phase 2 document GTR7-06-10e Rev 1, which is available from the GTR-7 Informal Group web site, in the folder for the 6th meeting (28 February, 2010, Brussels). The pulse has a delta-*v* of 17.6 $km.hr^{-1}$ and a peak acceleration of approximately 10.5 *g*. The corridor for the sled pulse is shown in Figure 2-1 and the detailed corridors are shown in Appendix A.

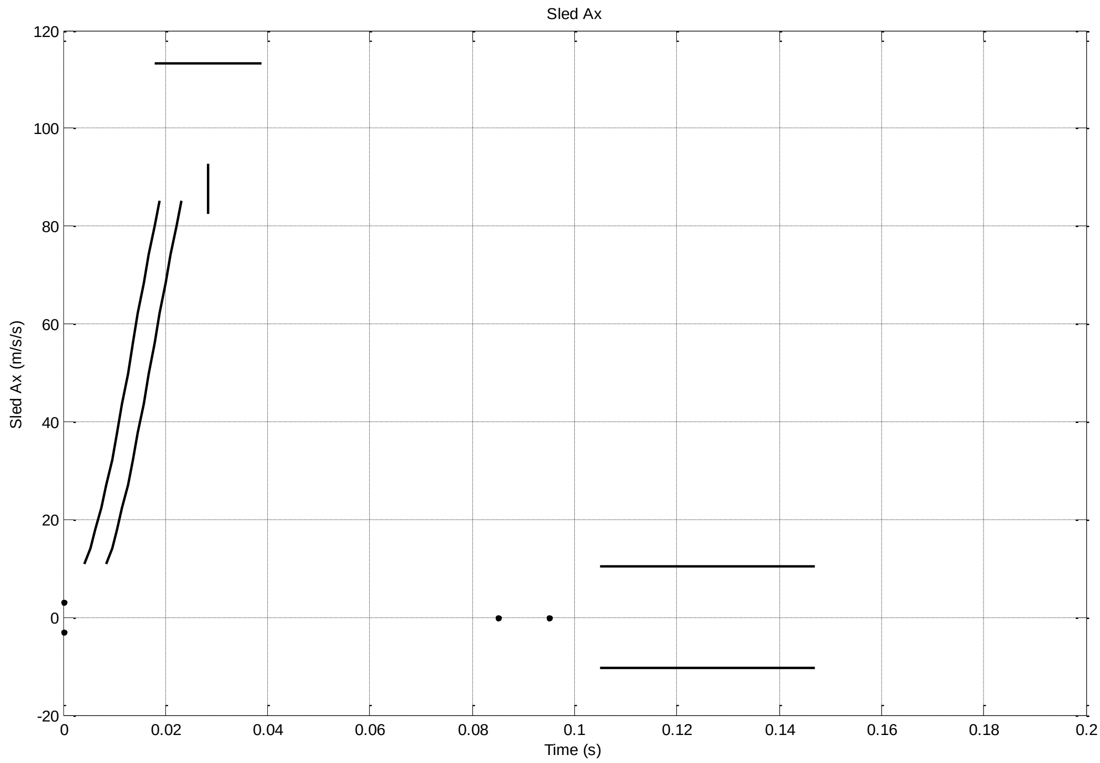


Figure 2-1: Draft GTR-7 Phase 2 Annex 9 pulse requirements

2.2 Test Seat

The testing was performed using a production car seat that was modified to ensure that the seat could be used repeatably for multiple tests. The philosophy for the modifications to the seat was to ensure that the interface between the dummy and the seat was as close as possible to the original vehicle seat, while being able to test multiple times with the same seat. In order to achieve this goal the seat was modified in the following ways:

- The seat base and seat back were separated, and the seat base fixed rigidly to the sled platform to at a height and tilt equivalent to that in a vehicle

- The seat back recliner mechanism was replaced with a 25 mm diameter bar and self-aligning bearings
    - This moved the pivot-point of the seat back slightly lower than in the original seat; this helped to prevent rubbing between the seat base and the seat back, which may otherwise have affected the repeatability of the test condition
- The original seat back recliner bar was reinforced to ensure that interaction between the dummy and the bar was repeatable
    - In pilot tests during the development of the seat it was found that the original recliner bar deformed in each test, which led to an inconsistent interaction with the dummy
    - The reinforced recliner bar will give a stiffer interaction between the dummy and the seat than the original equipment recliner bar; this may exaggerate any differences in dummy response due to variations in the pelvis of the dummy, but the modification made ensured a repeatable test condition
    - Other seats may have stiffer or less stiff structures in this region of the seat, and therefore have different interactions with the pelvis of the dummy; for example, a seat with a single recliner would have no bar joining the recliner mechanisms, which would be softer than the seat design used in this series
- The original seat back structure was strengthened to ensure that the seat frame did not distort in repeated tests and to provide a robust connection to the spring-damper system used to control seat back recline and rebound
- The seat back foam, supporting wires, and cover were retained
    - The seat back foam and supporting wires, lumbar adjust and so forth were retained exactly in their original form
    - The cover was removed in order to make the modifications to reinforce the seat; it was then re-fitted to the seat with all of the front anchorages replaced; upper rear anchorages were also replaced; part of the rear fabric of the cover was removed to allow space for the reinforcement structure, and the left- and right-hand sides of the cutaway fabric were held taut by cable ties running through metal eyelets in the fabric; finally, the lower anchorages (underneath the seat back) were extended with cable ties in order to keep the cover taut and to stop the rear of the cover riding up in successive tests
    - With these modifications, all aspects of the interface of the dummy to the seat cover were identical to the original seat; the modifications to the rear of the cover gave space for the reinforcement structures, but ensured that the cover was stable on the seat frame in the same way as the original seat
- A spring damper system to control the seat back recline and rebound response was developed especially for this application

    - The seat back was supported and controlled by two spring stacks during the recline action; the spring stiffness was tuned to give a maximum seat back recline angle of approximately 8°, which is typical for a modern European seat design
    - At maximum rearward rotation of the seat back, a clutch mechanism engaged two dampers; the dampers were tuned to return the seat to its original position within approximately 0.2°, with no overshoot.
- The original head restraint was removed from the seat back and mounted to the seat reinforcement structure
    - The original head restraint mounts included plastic parts that would not be robust in repeated testing
    - The replacement mounting bracket allowed the head restraint to be fixed at a range of backset positions, in increments of 20 mm
    - It should be noted that the head restraint had a homogeneous front face with a relatively flat surface and only a thin layer of foam padding, and that the front surface of the head restraint was stiffer than average; this may exaggerate differences between dummies, but provided a consistent and repeatable restraint of the head

The seat back reinforcement, spring-damper system, and supporting structures are shown in Figure 2-2. This also shows the large marker triad used as a datum for marker tracking, and smaller subsidiary marker triads used in the calibration of the marker tracking system.

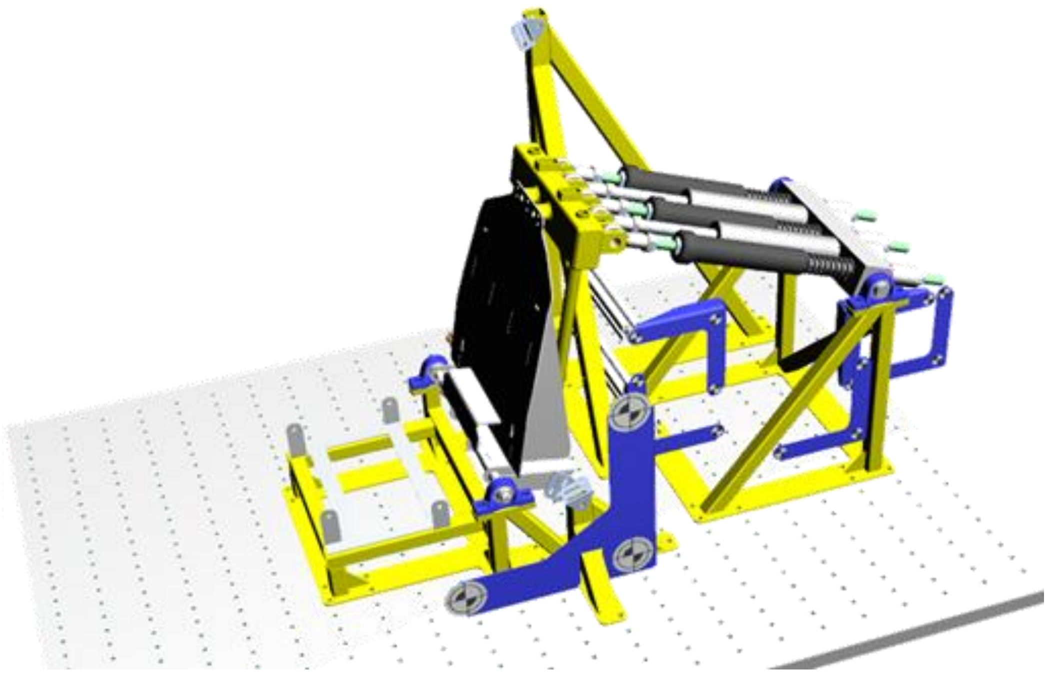


Figure 2-2: Structure of the TRL seat rig, showing the seat back reinforcement and spring damper system

Five seats were built, one of which was used for tuning tests to get the rig working. It was intended that the seat could be swapped for different parts of the test matrix (see Section 2.6) if necessary, or retained for all tests if it proved to be sufficiently robust.

2.3 Test Dummies

For the main test programme, four dummies from three laboratories were used. All four dummies were prepared by Humanetics, Heidelberg and built and certified to the GTR-7 TEG latest specification as of October 2011, including build and maintenance checklists, clothing, and joint stiffness settings. The dummies used in the main test programme were serial number 028, 068, 077 and 100. Each dummy was certified pre- and post-testing by Humanetics:

- TEG jacket test
- TEG without head restraint test
- TEG with head restraint test

Following testing, pelvis stiffness tests were also undertaken. Further information on the certification procedures may be found in Section 3.11. Some additional tests were performed with dummies serial number 006 and 007. These were fully refurbished by Humanetics, Heidelberg prior to testing. See Section 3.4 for more information on the build-level of these dummies.

Each dummy was fitted with the following instrumentation:

- Head tri-axial acceleration (Ax, Ay and Az)
- Upper neck forces and moments (Fx, Fz and My)
- C4 bi-axial acceleration (Ax and Az)
- Lower neck forces and moments (Fx, Fz and My)
- T1 left, T1 right and T8 acceleration (Ax)
- L1 bi-axial acceleration (Ax and Az)
- Pelvis tri-axial acceleration (Ax, Ay and Az)
- All instrumentation fully calibrated, with CFCs and CACs to Euro NCAP whiplash protocol v3.1 June 2011
- Data recording to ISO 6487:2002+A1:2008 or SAE J211-1:2003

2.4 Seating Procedure

2.4.1 BioRID Target Backset

The BioRID target backset was determined using the 3D H-point machine (HPM) (without head-room probe) and the Head Restraint Measurement Device (HRMD). The HPM and

HRMD were calibrated to the Euro NCAP 'Gloria' specification. The test procedure for determining the target backset was as defined in the Euro NCAP whiplash test protocol v3.1 (June, 2011) with one modification:

- The T-bar shall be held during steps 5.3.11 to 5.3.18 (Euro NCAP defines 5.3.11 to 5.3.17), in line with Annex 12 of the draft GTR (document GTR7-06-10 Rev 1, February 2011)

The BioRID target backset was measured three times and a mean value used. The same technicians, HPM and HRMD were used for all three tests. The same target backset was used for all tests, except for two tests discussed in Section 3.2. Therefore, this study includes no assessment of the repeatability and reproducibility of the target backset.

2.4.2 BioRID Installation

Once the target backset was determined, the BioRID was installed according to the procedure defined in the Euro NCAP whiplash test protocol v3.1 (June, 2011). The BioRID and seat positions were measured using a co-ordinate measuring machine (CMM) before every test, including the following locations:

- H-point left and right
- Head centre of gravity, chin and back of head mid
- OC (occipital condyle) pin left and right
- T1 pin, inner wand marker and outer wand marker
- Shoulder left and right
- Pelvis bracket inner wand marker and outer wand marker
- Knee bolt left and right
- Head restraint mid
- ST1, SRR, ST2, ST2', ST3', ST3, ST4, ST5

2.5 Film Analysis

Almost very test was filmed using two off-board cameras, with views as specified in the Euro NCAP whiplash test protocol v3.1 (June, 2011). The wide-view camera was calibrated for lens distortion, position and orientation and the quality of calibration was assessed using ISO 8721:2010. For six tests, the wide-view off-board camera was replaced with an on-board camera. Further details of the camera set-up and calibration may be found in TRL report CPR1302.

2.6 Test Matrices

The test matrices for the test programme that was originally planned are shown in Appendix B. The test matrices were in five parts and can be summarised as follows:

Phase 1: Repeatability and Reproducibility tests at far head restraint position (5 repeats with each of four dummies – total 20 tests)

Phase 2: Repeatability and Reproducibility tests at near head restraint position (5 repeats with each of four dummies – total 20 tests)

Phase 3: Repeatability and Reproducibility tests at mid head restraint position (5 repeats with each of four dummies – total 20 tests)

Phase 4: Seating procedure tests (3 repeats with 3 dummies – total 9 tests)

Phase 5: On-board camera tests (3 repeats at two head restraint positions with one dummy – total 6 tests)

Total: 75 tests

The above test matrix was to be run using BioRID II dummies with serial numbers 028, 068, 077 and 100, which were made available to the programme from three laboratories.

However, following the completion of the first 20 tests in Phase 1 of the test matrix, it became clear that there were significant differences between the responses of the four dummies, particularly with regard to the T1 shear force Fx and the upper neck shear force Fx and moment My.

Following discussion with the EC Project Officer, it was agreed that the remainder of the test matrix should be revised to investigate the cause of the observed differences between the dummies, and to suggest ways in which the reproducibility of the dummy responses could be improved. The test matrix was therefore reconfigured as follows, all using seat S2 with a far head restraint position:

Phase 1: Baseline repeatability and reproducibility tests with dummies 028, 068, 077 and 100 (5 repeats with each dummy – total 20 tests)

Phase 2: Tests with dummy 068 with modified backset or H-point (total 4 tests)

Phase 3: Baseline repeatability and reproducibility tests with dummies 006 and 007 (3 repeats with each dummy – total 6 tests)

Phase 4: Tests with dummy 068 and 077 (the outlying dummies from Phase 1), with parts such as the pelvis or spine swapped between dummies (total 15 tests)

Phase 5: Tests with dummy 068 and 077 rebuilt to their original configuration (no parts swapped) (total 5 tests)

Phase 6: Tests with dummy 006 and 007, using the pelvis from dummy 068 or 077 (total 4 tests)

Phase 7: Test with dummy 077 with new bumpers at the top two thoracic spine positions (total 1 test)

Phase 8: Tests with dummy 068 and 077, following refurbishment of the spines intended to standardise the response of the dummies (total 4 tests)

Phase 9: Tests with dummy 100 with an on-board camera (total 6 tests)

Total: 65 tests

It should be noted that at the time of testing the GTR-7 Phase 2 Informal Group had not finalised its work on injury criteria, so it was not known which measurement channels in the dummies were actually required for use in the draft GTR. Therefore, all channels were included in the analysis.

It should also be noted that the effort involved in the revised test programme was considerably greater than that originally planned, with a lot of building and re-building of the dummies between tests, as well as additional analysis. Phase 8 of the programme also required refurbishment of the dummies at Humanetics prior to testing. However, all parties involved in the testing (TRL, BASt and Humanetics) agreed to absorb the additional costs up to the number of tests that could be completed by the end of February, which was the latest that tests could be undertaken without extending the project deadline. In total 65 tests were performed.

The actual test matrix is shown in Table 2-1 to Table 2-8. The tests with on-board camera in Table 2-9 are analysed in TRL report CPR1302.

Table 2-1: Test matrix Phase 1: baseline tests with dummies 028, 068, 077 and 100

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
1	S2	100	Rear	Off-board	Baseline test at far HR position. NB: head restraint mounting not fully tightened – head/neck results may be affected
2	S2	077	Rear	Off-board	Baseline test at far HR position
3	S2	077	Rear	Off-board	Baseline test at far HR position
4	S2	100	Rear	Off-board	Baseline test at far HR position
5	S2	100	Rear	Off-board	Baseline test at far HR position
6	S2	077	Rear	Off-board	Baseline test at far HR position
7	S2	068	Rear	Off-board	Baseline test at far HR position
8	S2	028	Rear	Off-board	Baseline test at far HR position
9	S2	068	Rear	Off-board	Baseline test at far HR position
10	S2	028	Rear	Off-board	Baseline test at far HR position
11	S2	028	Rear	Off-board	Baseline test at far HR position
12	S2	068	Rear	Off-board	Baseline test at far HR position
13	S2	068	Rear	Off-board	Baseline test at far HR position
14	S2	028	Rear	Off-board	Baseline test at far HR position
15	S2	100	Rear	Off-board	Baseline test at far HR position
16	S2	100	Rear	Off-board	Baseline test at far HR position
17	S2	077	Rear	Off-board	Baseline test at far HR position
18	S2	077	Rear	Off-board	Baseline test at far HR position
19	S2	100	Rear	Off-board	Baseline test at far HR position
20	S2	068	Rear	Off-board	Baseline test at far HR position

Table 2-2: Test matrix Phase 2: tests with dummy 068 with modified backset or H-point

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
21	S2	068	Rear	Off-board	Dummy seated as in baseline tests, but with no attempt to match the backset. NB: 95 mm backset *cf.* 75 mm in baseline tests
22	S2	068	Rear	Off-board	Dummy seated as in test 21, but with head restraint moved 20 mm forward to match 75 mm backset from baseline tests
48	S2	068	Rear	Off-board	Foam placed on the seat base (under pelvis and thighs) to raise H-point by approximately 30 mm
49	S2	068	Rear	Off-board	Repeat of test 48

Table 2-3: Test matrix Phase 3: baseline tests with dummies 006 and 007

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
23	S2	006	Rear	Off-board	Baseline test with dummy 006
23	S2	006	Rear	Off-board	Baseline test with dummy 006
25	S2	007	Rear	Off-board	Baseline test with dummy 007
26	S2	007	Rear	Off-board	Baseline test with dummy 007
27	S2	007	Rear	Off-board	Baseline test with dummy 007
31	S2	006	Rear	Off-board	Baseline test with dummy 006

Table 2-4: Test matrix Phase 4: parts swapped between dummies 068 and 077

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
28	S2	077	Rear	Off-board	077 with 068 spine
29	S2	077	Rear	Off-board	077 with 068 spine
30	S2	077	Rear	Off-board	077 with 068 spine and jacket
32	S2	068	Rear	Off-board	068 with 077 spine
33	S2	068	Rear	Off-board	068 with 077 spine
34	S2	068	Rear	Off-board	068 with 077 spine and jacket (pin 3L missing)
35	S2	068	Rear	Off-board	068 with 077 spine and jacket
36	S2	068	Rear	Off-board	068 with 077 spine, jacket pelvis and legs
37	S2	068	Rear	Off-board	068 with 077 spine, jacket pelvis and legs
38	S2	077	Rear	Off-board	077 with 068 spine, jacket and pelvis
39	S2	077	Rear	Off-board	077 with 068 spine, jacket and pelvis
40	S2	068	Rear	Off-board	068 with 077 pelvis
41	S2	068	Rear	Off-board	068 with 077 pelvis
42	S2	077	Rear	Off-board	077 with 068 pelvis
43	S2	077	Rear	Off-board	077 with 068 pelvis

Table 2-5: Test matrix Phase 5: dummies 068 and 077 rebuilt (i.e. dummy 068 rebuilt with only parts from dummy 068)

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
45	S2	077	Rear	Off-board	077 rebuilt
46	S2	068	Rear	Off-board	068 rebuilt
47	S2	068	Rear	Off-board	068 rebuilt
50	S2	077	Rear	Off-board	077 rebuilt
51	S2	077	Rear	Off-board	077 rebuilt

Table 2-6: Test matrix Phase 6: dummies 007 and 007 with pelvises from 068 or 077

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
44	S2	007	Rear	Off-board	007 with 068 pelvis
52	S2	006	Rear	Off-board	006 with 077 pelvis
53	S2	006	Rear	Off-board	006 with 068 pelvis
54	S2	007	Rear	Off-board	007 with 077 pelvis

Table 2-7: Test matrix Phase 7: dummy 077 with new bumpers at the top two locations of the rear thoracic spine

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
55	S2	077	Rear	Off-board	077 with new bumpers – T2 and T3 rear

Table 2-8: Test matrix Phase 8: dummy 068 and 077 tests with refurbished spines

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
62	S2	068	Rear	Off-board	068 with refurbished spine
63	S2	068	Rear	Off-board	068 with refurbished spine
64	S2	077	Rear	Off-board	077 with refurbished spine
65	S2	077	Rear	Off-board	077 with refurbished spine

Table 2-9: Test matrix Phase 9: tests with on-board camera

Test No.	Seat No.	Dummy No.	Head Restraint Position	Camera Position	Comment
56	S2	100	Rear	On-board	On-board camera test
57	S2	100	Rear	On-board	On-board camera test
58	S2	100	Rear	On-board	On-board camera test
59	S2	100	Front	On-board	On-board camera test
60	S2	100	Front	On-board	On-board camera test
61	S2	100	Front	On-board	On-board camera test

2.7 Certification

2.7.1 Without-Head-Restraint Certification Test

The BioRID II dummy is certified using a mini-sled based test procedure. A 37.6 kg pendulum impactor provides the input energy, and this is transferred to a min-sled via a large elastomer bumper. The head, neck and torso of the dummy are mounted to the sled via the pelvis adaptor plate as shown in Figure 2-3. External potentiometers are attached across four sections of the spine and these, along with selected dummy accelerations, forces and moments, are measured during the rear impact. Corridors have been defined for most of these measurements, and these are used to control the performance of the dummy. There is no head restraint in the standard certification test. A more detailed description of the certification test without head restraint may be found in the document, 'Certification Procedures for the BioRID II Crash Test Dummy', November 2010[2].

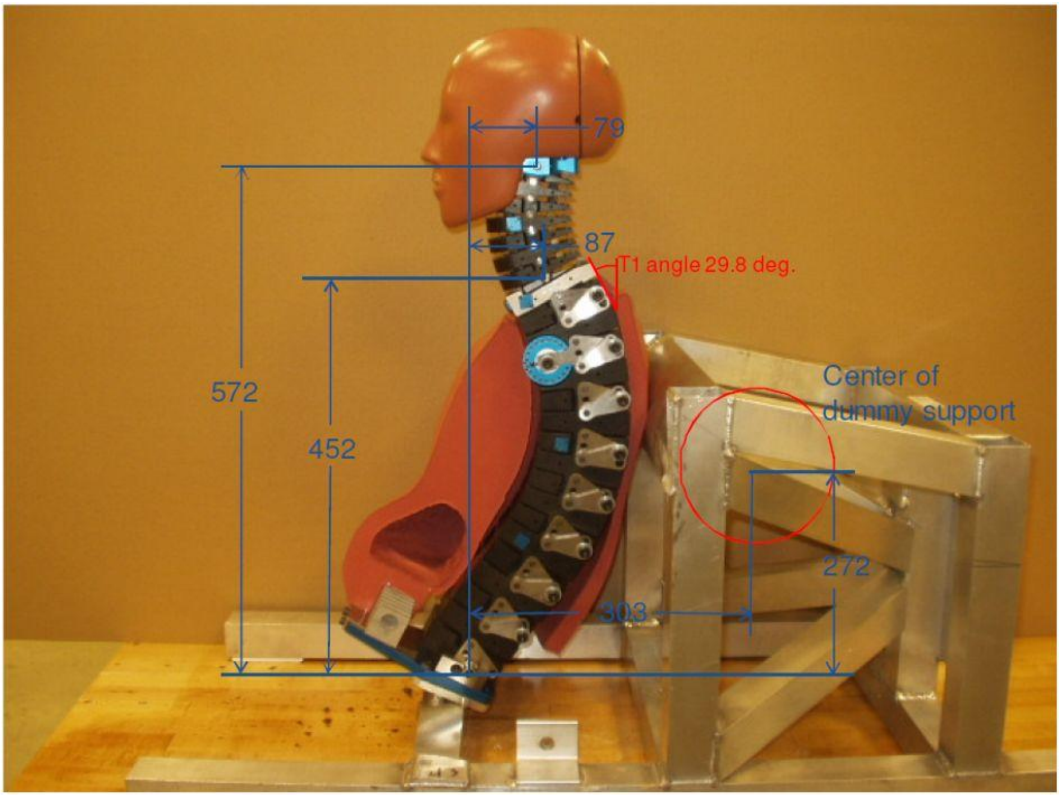


Figure 2-3: BioRID without-head-restraint certification set-up

In addition to the certification of the dummy, a test is also defined for certifying the mini-sled, and in particular the performance of the elastomer interface between the pendulum impactor and the mini-sled.

[2] Available from www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/gtr7phase2_0.html, file name TEGID-22 - Certification Procedures for the BioRID II Crash Test Dummy

During the last several years, the BioRID Technical Evaluation Group (TEG) and the dummy manufacturer (Humanetics) have identified the need for additional certification tests to control different aspects of the performance of the dummy. These tests include the following:

- Mini-sled test with head restraint
- Jacket stiffness test
- Pelvis stiffness tests

These tests are described briefly in the following sections.

2.7.2 With-Head-Restraint Certification Test

The with-head-restraint certification test uses the same mini-sled as the without head restraint certification test, with the addition of a rigid, adjustable head restraint assembly. A heavier (118.5 kg) impactor provides the energy input to the with head restraint certification test, again via a calibrated elastomer interface. The general configuration of the head restraint is shown in Figure 2-4. A more detailed description of the certification test with head restraint may be found in the document, 'Certification Procedures for the BioRID II Crash Test Dummy', November 2010 (see footnote page 17). It should be noted that draft corridors have been proposed for the sled response in this test procedure, but not for the response of the dummy. Specific dummy requirements are expected to be developed as more experience is gained with the test procedure.

Figure 2-4: BioRID with head restraint certification set-up

2.7.3 Jacket Stiffness Certification Test

The jacket certification test is designed to assess the stiffness of the jacket material in compression. The jacket is mounted on the same min-sled as the standard certification test, via a special mounting assembly. The jacket is impacted directly by a 14 kg pendulum impactor and the primary certification requirement is the impactor force, which is derived from measurement of the impactor acceleration. Figure 2-5 shows the jacket mounted on the mini-sled. It can be observed that the jacket is impacted on the front surface, and the rear surface of the jacket, which forms the majority of the interface between the dummy and the seat, is not loaded in the test. However, it is understood that the test assesses the bulk properties of the material.

A full description of the jacket certification test, as well as draft performance requirements, may be found in the document, ‘Certification Procedures for the BioRID II Crash Test Dummy’, November 2010 (see footnote page 17).

Figure 2-5: BioRID jacket certification set-up

2.7.4 Pelvis Stiffness Certification Tests

The pelvis certification test was developed several years ago, but has not been in regular usage. The test is very similar to the jacket test, with a pendulum impact directly to the bottom or rear of the pelvis, as shown in Figure 2-6. This draft certification test is not included in the certification manual at the time of writing. It can be seen in Figure 2-6 that the rear impact is high up on the pelvis (the pelvis is inverted for the test), and is above the level of the cut-away that gives access to the accelerometer mounts. It may be also be worth considering a test that interacts with this part of the pelvis flesh.

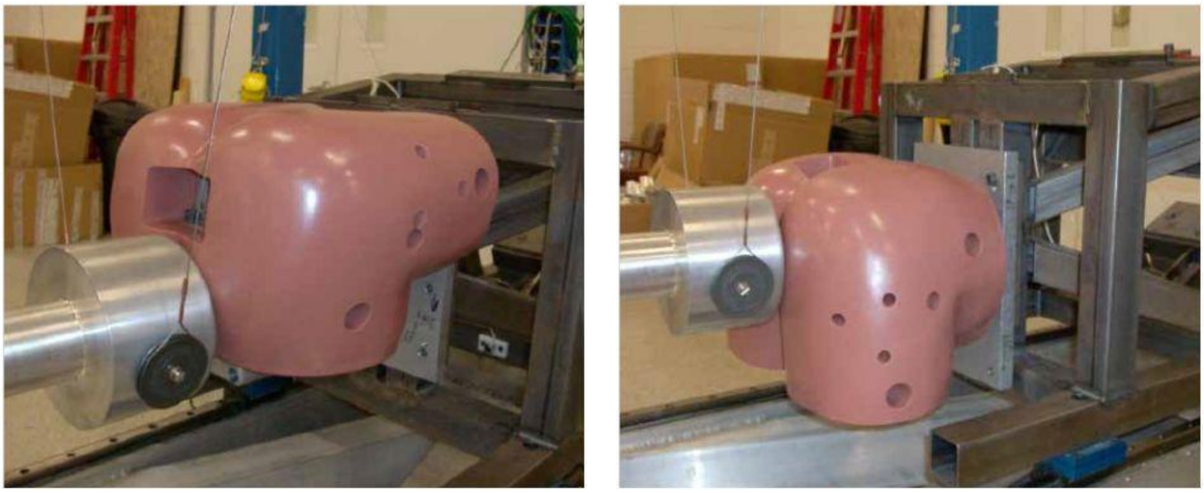


Figure 2-6: BioRID pelvis certification set-up: rear impact left; base impact right

3 Results

The results from the test programme are presented in this section of the report, with the results of each Phase of the test matrix reported separately. The main body of the report contains selected graphs, with the full set of graphs reproduced in the appendices.

Key:

In the all of the graphs plotted in this report, the following key is used for the line styles:

-	Solid	Original spec, possibly with changes to seat
..	Dotted	Swapped pelvis
--	Dashed	Swapped spine (possibly also jacket)
-.	Dash-Dot	Swapped pelvis & spine (possibly also jacket and/or legs)

The following colour code is used for each dummy:

Dummy serial no.	Colour	Notes
028	Magenta	
068	Green	Including shades of green for different types of test, such as swapped parts
077	Red	Including shades of red/orange for different types of test, such as swapped parts
100	Blue	
006	Grey	Including shades of grey for different types of test, such as swapped parts
007	Cyan	Including shades of light blue for different types of test, such as swapped parts

The following sign convention is used for each dummy (SAE J211-1:2007):

Instrument	Measure	Description
Upper and lower neck loads	+ Fx	Head rearward, chest forward
	+ Fz	Head upward, chest downward (tension)
	+ My	Chin toward sternum (flexion)
Head, spine and pelvis accelerations	+ Ax	Forwards
	+ Ay	Right
	+ Az	Down

3.1 Phase 1: Baseline Tests with Dummies 028, 068, 077 and 100

As noted in Table 2-1, the baseline tests with dummies 028, 068, 077 and 100 comprised 5 repeat tests with each dummy. The order in which each dummy was tested is shown by the key in each figure. The order was not completely random, because dummies 028 and 068 were still undergoing certification when the testing was started. However, within this constraint the order of tests was varied as much as possible.

A complete set of figures for these tests may be found in Appendix C.

3.1.1 Pulse

The sled pulse for the first 20 tests is shown in Figure 3-1, along with the draft GTR-7 Phase 2 corridors from document GTR7-06-10. The sled pulse complies with the requirements well, except for a small peak acceleration at 120 ms, which corresponds with the engagement of the dampers in the seat back. This feature would therefore normally not be present with a conventional seat. In addition, it occurred after all of the peak dummy accelerations, forces and moments and it was therefore considered that this would not influence the conclusions of this work.

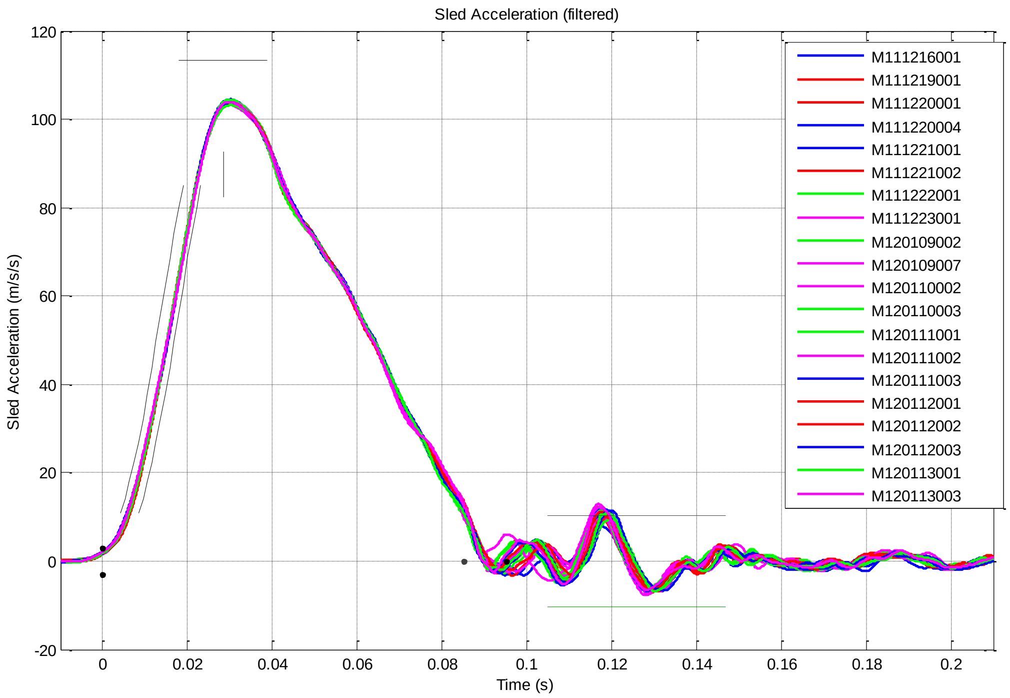


Figure 3-1: Sled acceleration pulse and draft GTR-7 Phase 2 corridors

3.1.2 Seat Response

The displacement of the seat back was measured using LVDTs (Linear Variable Differential Transformers) mounted alongside the left and right spring stacks supporting the seat back. From this, the dynamic seat back angle could be calculated. Figure 3-2 shows the seat back angle from the left-hand LVDT, with a very similar measurement for the right-hand side shown in Appendix C.1. These graphs demonstrate that the seat back recline angle was just over 8°, and that it was very repeatable. Some dummy-dependency can be observed in the seat back response; for instance, it can be observed that dummy 077 consistently rotated the seat slightly further rearward than dummy 028.

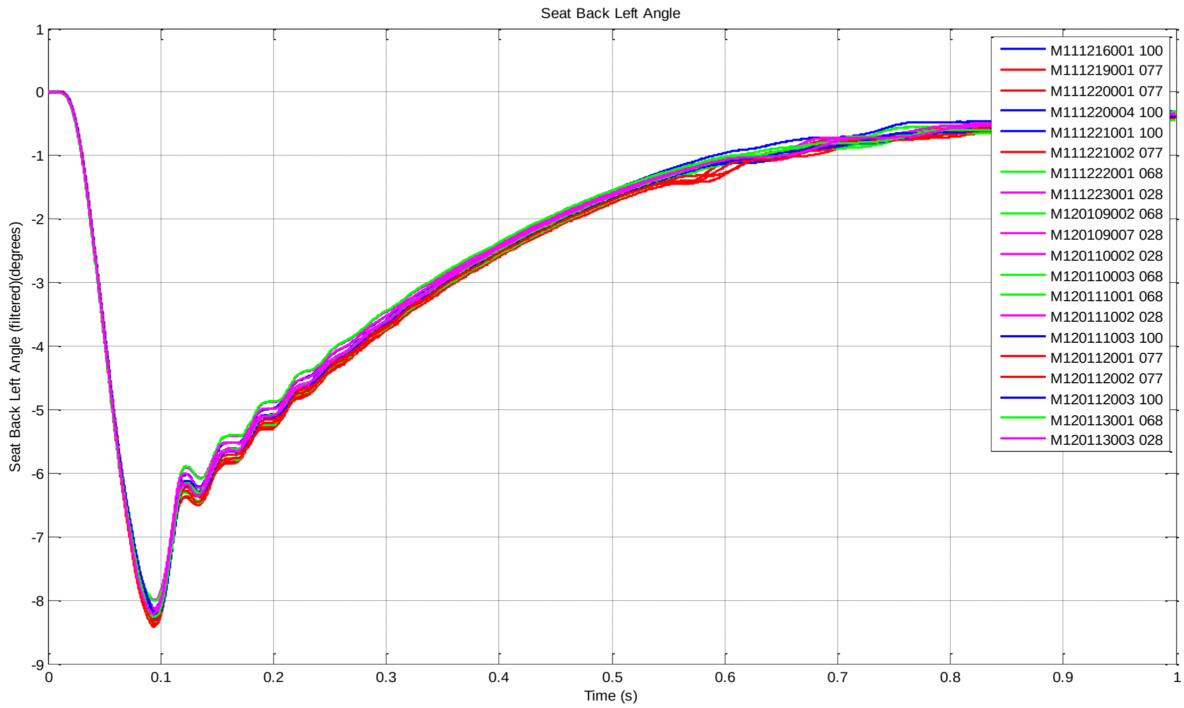


Figure 3-2: Sled acceleration pulse and draft GTR-7 Phase 2 corridors

3.1.3 Dummy Positioning

The co-ordinates of various BioRID II features, as well as a number of seat marker locations, were digitised using a co-ordinate measuring machine before every test, as shown in Figure 3-3. The co-ordinates for the left and right H-points were ±5 mm across all 20 baseline tests. In general, the H-point heights were similar, except for dummy 028 where the H-point was approximately 4 mm lower (see Figure 3-4). It should be noted that the H-point tool was quite loose in some of the dummies tested and it was easily possible to move the tool more than ±5 mm. Therefore, within the accuracy of the H-point tool, it is not possible to comment for certain whether dummy 028 was lower in the seat.

After testing, analysis of the dummy and seat co-ordinates that were measured before each test showed that the head restraint was bending rearward slightly in each test. This meant that the dummies had to be seated in a progressively more head-rearward posture in each test. The head restraint target for the BioRID backset moved rearwards by 20 mm between tests 1 and 20, including 10 mm during the first three tests and 10 mm over the following 17 tests. It is known that the head restraint was not adequately secured in the first test and it may not have been tight enough in the second and third test. Once the head restraint was secured more rigidly, the permanent deflection of the head restraint in each test was approximately 0.6 mm.

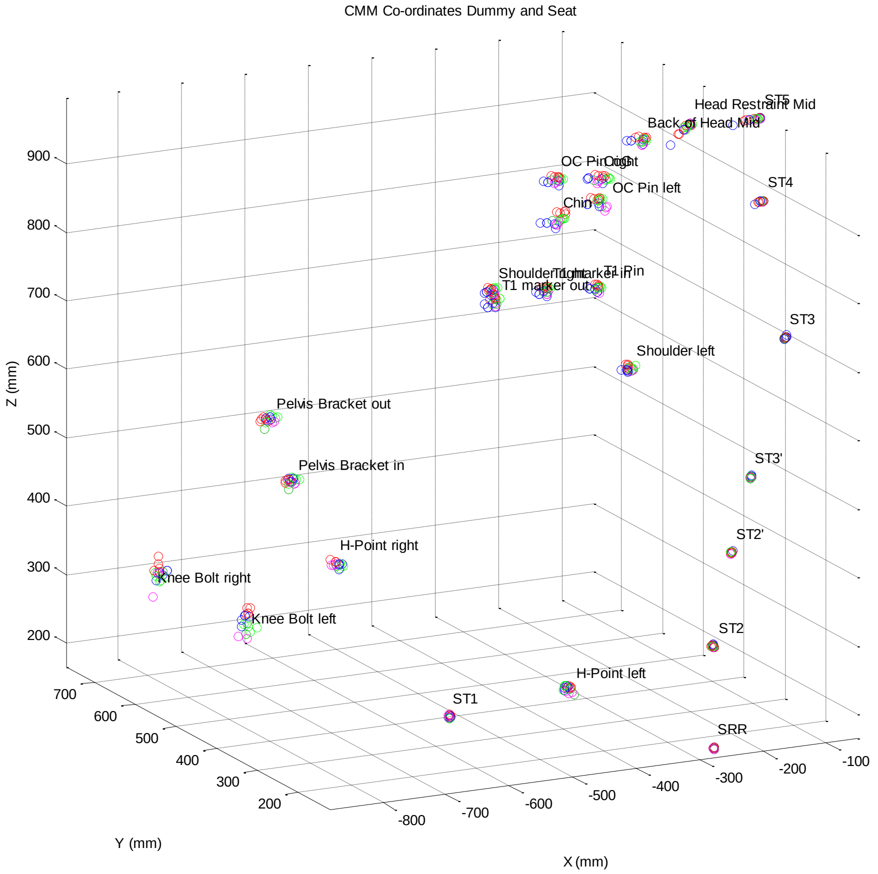


Figure 3-3: Overview of seat and dummy co-ordinate data

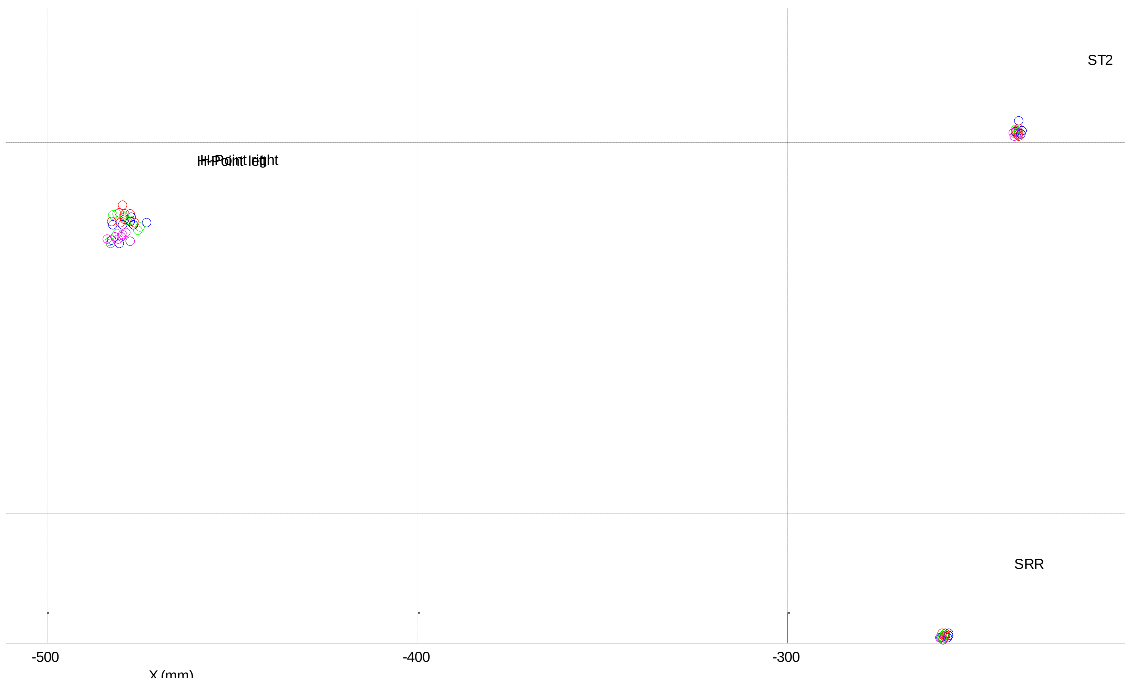


Figure 3-4: Distribution of left and right H-points (seat pivot point SRR also shown to illustrate the precision with which an unvarying marker could be measured across multiple tests)

3.1.4 Dummy Responses

The X-axis accelerations measured in the dummy are shown in Appendix C.2. The pelvis acceleration Ax showed two rates of loading, a higher rate of loading for dummies 028 and 077, and a lower rate of loading for dummies 068 and 100. Dummies 028 and 077 appeared to have notably harder pelvis flesh than dummies 068 and 077. No significant difference in L1 or T8 Ax was observed. T1 Ax showed a first peak with similar timing (70 ms) and magnitude (130 $m.s^{-2}$) to the peak L1 and T8 Ax, followed by a larger, more variable peak of between 160 and 220 N. This second peak showed some correlation with jacket stiffness in that dummies 028 and 077 had the stiffest jackets and the stiffest T1 response, but dummy 100 showed a similar T1 response to dummy 068 despite having a notably softer jacket in the jacket certification test. This could be because the jacket certification test loads the front of the jacket, whereas the much thinner rear of the jacket is loaded in seat tests. It should also be noted that the jacket opening is along the centre line of the spine and that when the jacket is installed on the dummy, this gap may not be completely consistent. This could lead to a different effective stiffness of the flesh over the spine, and therefore potentially a different interaction with the seat back.

Inspection of the seat showed signs of slight hard contact between a wire in the upper seat back and the supporting structure that was added to improve the robustness of the seat for repeated testing. It would appear that the dummy response at L1 and T8 was entirely due to the OEM seat structure, and that at the pelvis and T1 there was additional contact with the underlying structure. This contact was slight at T1, but somewhat more severe at the pelvis. During initial trials of a prototype modified seat, it was found that the bar that joined the left and right recliner mechanisms was being loaded by the pelvis of the dummy and was bending. In order to ensure that this interaction was as repeatable as possible, the OEM recliner bar was surrounded with a more rigid secondary part. Thus the pelvis interaction with the seat in these tests is likely to be somewhat stiffer than in the original seat, although it should be noted that other seat designs could contain stiffer recliner bars than our original seat, or indeed other seat structures.

The C4 Ax measurements were less repeatable than the other X-axis accelerations, with no clear grouping of the peak responses for each dummy as was seen with the Ax measurements further down the spine. The low response for one of the tests with dummy 100 was the first test, with a loose head restraint. This caused the peak head acceleration to be lower and later than for the other tests. The same effect is observed for the head Ax response in the first test. The head Ax response was otherwise reasonably repeatable, generally with a slightly lower peak acceleration for dummies 068 and 100 compared with dummies 028 and 077.

The Z-axis accelerations measured in the dummy are shown in Appendix C.3. The pelvis acceleration was very repeatable, although with distinctly different responses for each dummy as shown in Figure 3-5. Pelvis Az was always positive for dummy 068, whereas the other dummies showed a negative acceleration at 90 ms (time of peak head restraint contact). The Z-axis at L1, C4 and the head were generally repeatable and more reproducible than the X-axis accelerations, particularly considering the relatively low absolute value of these measurements.

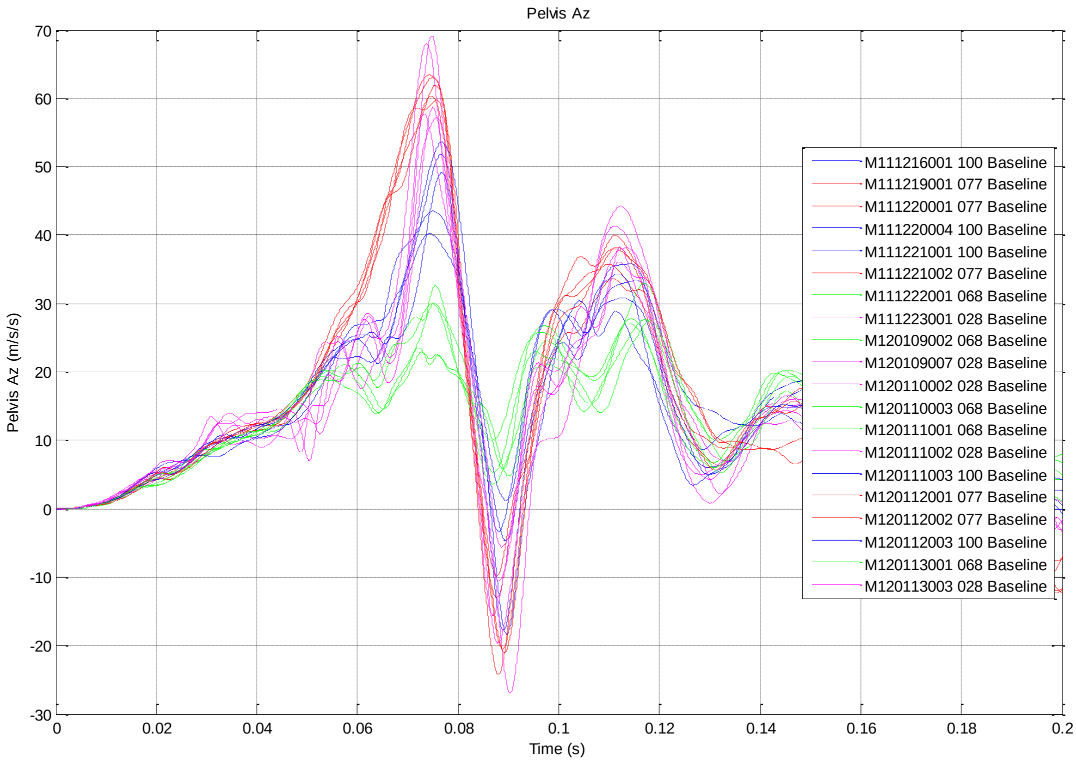


Figure 3-5: Pelvis Z-axis acceleration in the baseline tests

T1 and upper neck forces and moments are shown in Appendices C.4 and C.5 respectively. The X-axis shear force at both load cells was very repeatable and reproducible across all 20 tests, with a peak force of approximately 400 N at T1 and -300 N at the upper neck. As may be expected, the loose head restraint in the first test caused a marked reduction in upper neck Fx compared with the other tests. The graphs also show a very noisy signal for several tests, which was due to a poor connection in the converter cables that were necessary to allow the dummy to be plugged into the data acquisition system.

T1 and upper neck Z-axis forces were repeatable, but not very reproducible. Peak T1 Fz, occurring at 90 ms, varied between 200 N for dummy 068 and over 400 N for dummy 077. Peak upper neck Fz, also at 90 ms, varied from 600 N for dummy 068 and 1100 N for dummy 077.

T1 My was repeatable, and quite reproducible considering the small moment being measured (-6 to -9 Nm peak extension at 90 ms, and 4-6 Nm peak flexion at 110 ms – see Figure 3-6).

The upper neck moment about the Y-axis is shown in Figure 3-7. This clearly shows good repeatability and inadequate reproducibility. One curve from dummy 068 is clearly different, which was attributed to a loose connector. The first test with dummy 100, with the loose head restraint, shows a later peak extension moment than the other tests as would be expected. It should be noted that peak head restraint contact (e.g. peak head Ax) occurred at 90 ms, and that by the time of peak neck extension moment at 110 ms most of the acceleration channels are at or close to zero. This indicates that the variable peak upper neck My occurs when the dummy has little external loading.

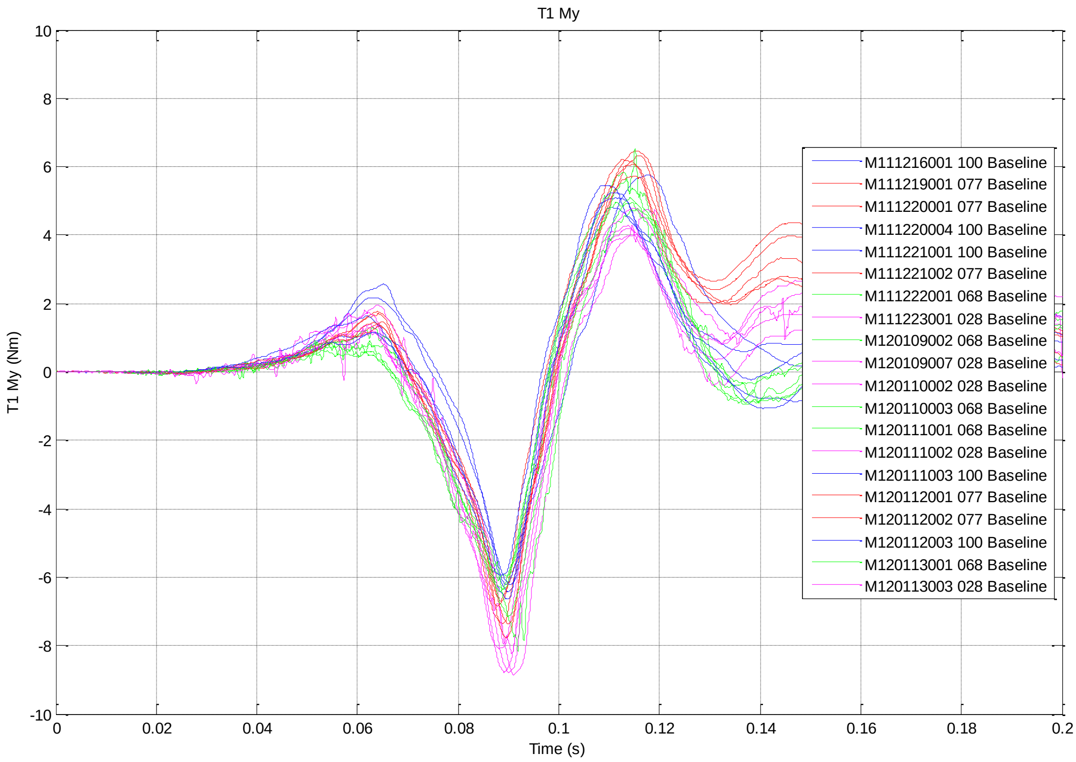


Figure 3-6: T1 moment about the Y-axis

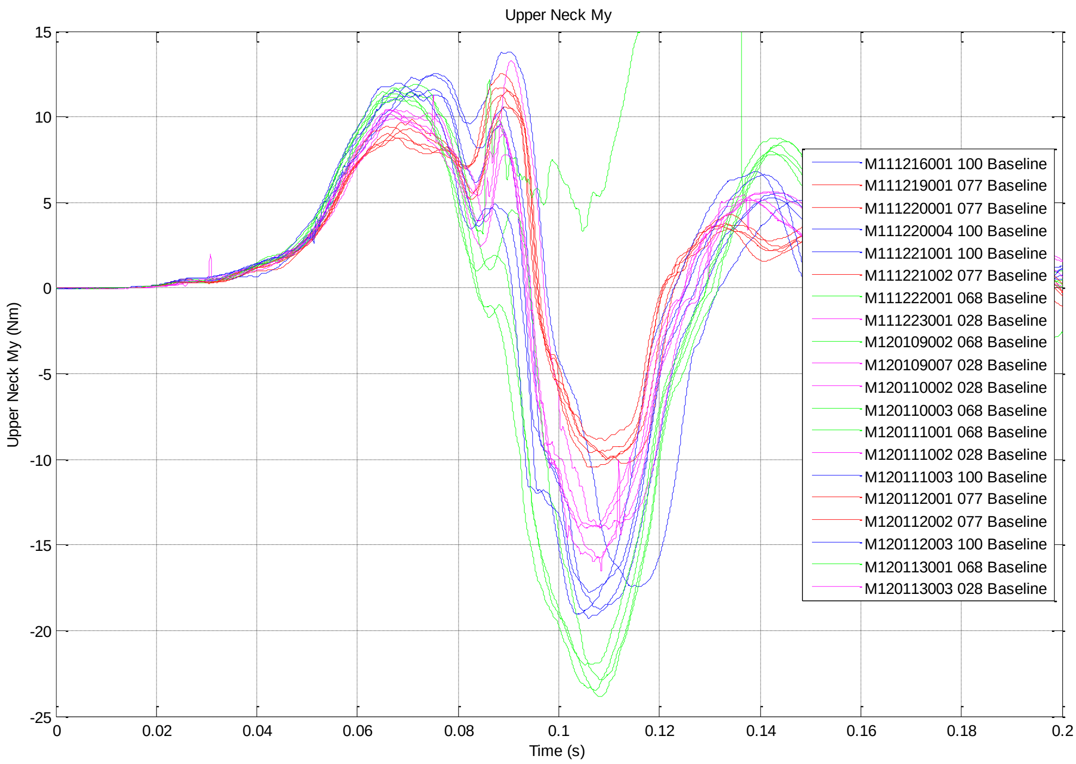


Figure 3-7: Upper neck moment about the Y-axis

Appendix C.6 shows the dummy responses including the whole rebound phase for several channels. It can be observed that:

- For several channels, the measurements made when the dummy has rebounded and is restrained by the seat-belt were comparable to the loads in the region normally assessed (upper neck Fx and upper neck My flexion)
- For several channels, the measurements when the dummy is restrained by the seat-belt after rebounding were markedly higher than the loads in the timescale normally assessed (T1 Fz and T1 My)

The rebound in these tests may have been more vigorous than a standard seat test. However, the seat back was critically damped in rebound - i.e. the damping returned the seat back to its initial position with no overshoot – which was intended to avoid excessive rebound loading on the dummy.

3.1.5 Dummy Kinematics

The following figures show exemplar tests from the baseline 20 tests. In each case, each figure shows an image of dummy 068 overlaid with either dummy 100, 028 or 077. Each figure shows the overlay at a particular time:

- Figure 3-8: T-zero
- Figure 3-9: 78 ms, which was a typical head restraint contact time for all four dummies
- Figure 3-10: 100 ms, which is aligned with the start of the large difference in upper neck My

In each case, there is relatively little difference between the dummies up to 78 ms. However, by 100 ms dummy 068 has moved further up and rotated further back than each overlaid dummy. Dummy 077 can be seen to have moved upwards and rotated backwards very little, with slightly greater upward and rotational motion for dummy 028, and more again for dummy 100. These motions appear to be consistent with the change in upper neck moment shown in Figure 3-7. That is, greater upward and rotational motion correlates with greater upper neck extension moment at 100 ms.

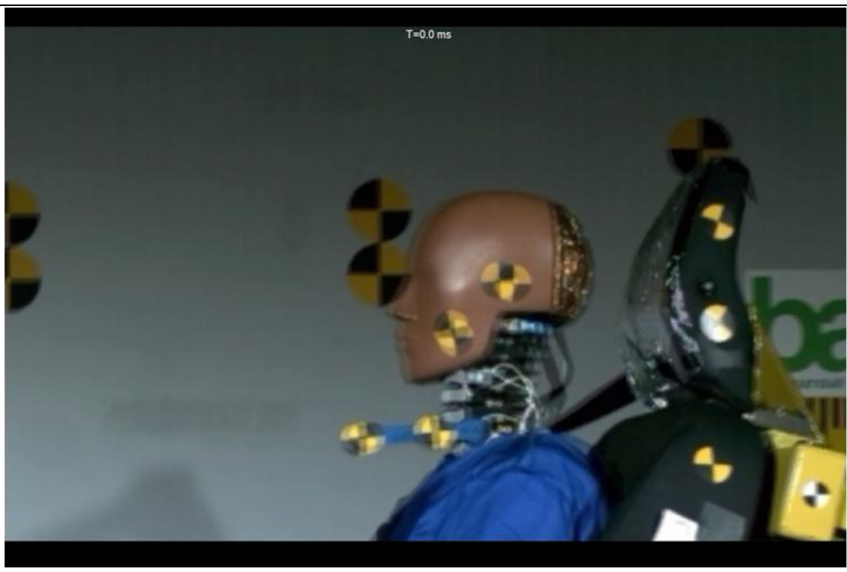
068-100 t-zero	
068-028 t-zero 068 is higher and rearward	
068-077 t-zero	

Figure 3-8: Overlays of dummy 068 and each other dummy at t-zero

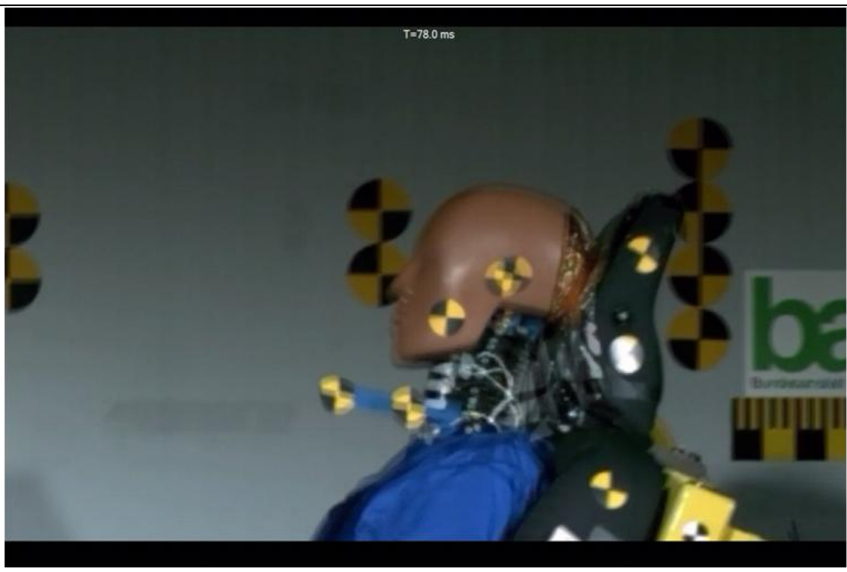
068-100 78 ms (typical HRCT)	
068-028 78 ms (typical HRCT)	
068-077 78 ms (typical HRCT)	

Figure 3-9: Overlays of dummy 068 and each other dummy at 78 ms (~HRCT)

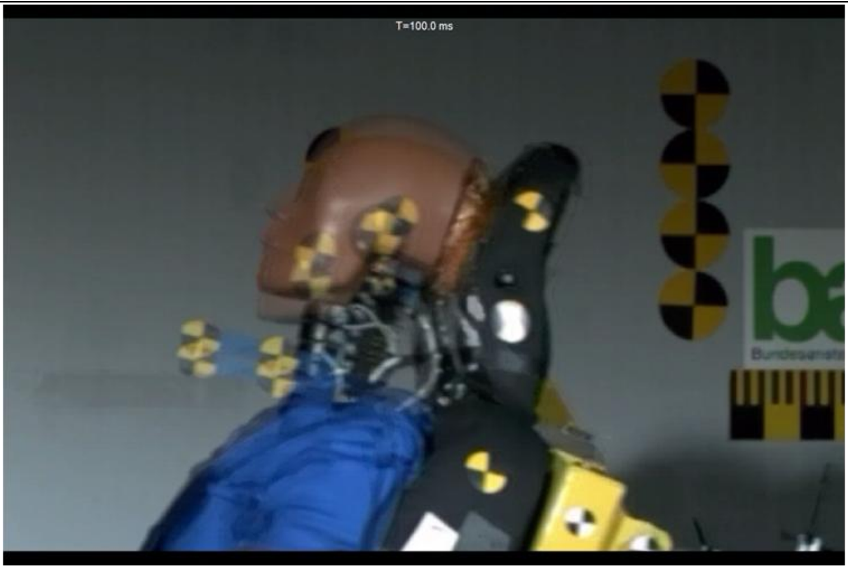
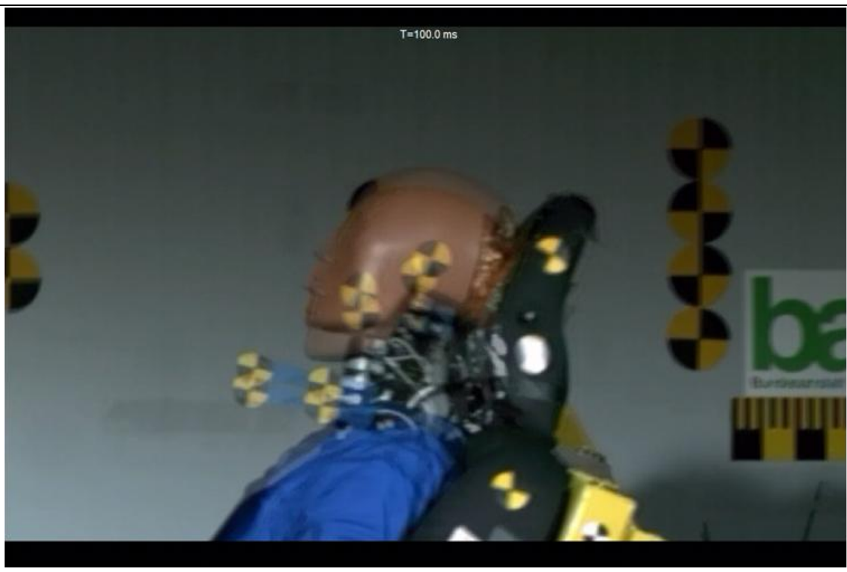
068-100 100 ms	
068-028 100 ms 068 is higher and rotated rearward	
068-077 100 ms 068 is higher and rotated rearward	

Figure 3-10: Overlays of dummy 068 and each other dummy at 100 ms

The dummy kinematics in the baseline tests was subsequently assessed based on the marker tracking undertaken in a separate project. The methods and results of this are discussed in more detail in TRL report CPR1302, but some key findings relating to dummy performance are reproduced here for convenience.

Figure 3-11 shows the head angle relative to the sled co-ordinate system, Figure 3-12 the T1 angle relative to the sled, and Figure 3-13 the pelvis angle relative to the sled. It is clear that each dummy has a distinctive response (indicating reasonable repeatability), but that reproducibility is poor. The pelvis angle in particular is markedly different between dummies. The pelvis of dummy 077 (with stiff pelvis flesh) immediately goes into extension (anti-clockwise rotation of the pelvis wand, when viewed from the left-hand side of the dummy). In contrast, dummies 068 and 100 (with soft pelvis flesh) go into flexion during the interaction between the dummy and the seat back, and only go into extension once the dummy has rebounded. Dummy 028 (with very stiff pelvis flesh) showed a very brief flexion response, moving quickly into extension early in the seat back interaction (just after head restraint contact).

The relative rotation between the head and T1 is shown in Figure 3-14. Again, the reproducibility of this parameter is poor compared to the repeatability. Dummy 077 shows neck *flexion* throughout the rear impact event – the head never goes into extension relative to the T1. Dummy 068, however, shows an initial flexion response, with a maximum at the time of peak head restraint contact. It then has an extension response at the time of peak upper neck My extension moment. These variations seem well correlated to the variations in upper neck My noted in Section 3.1.4.

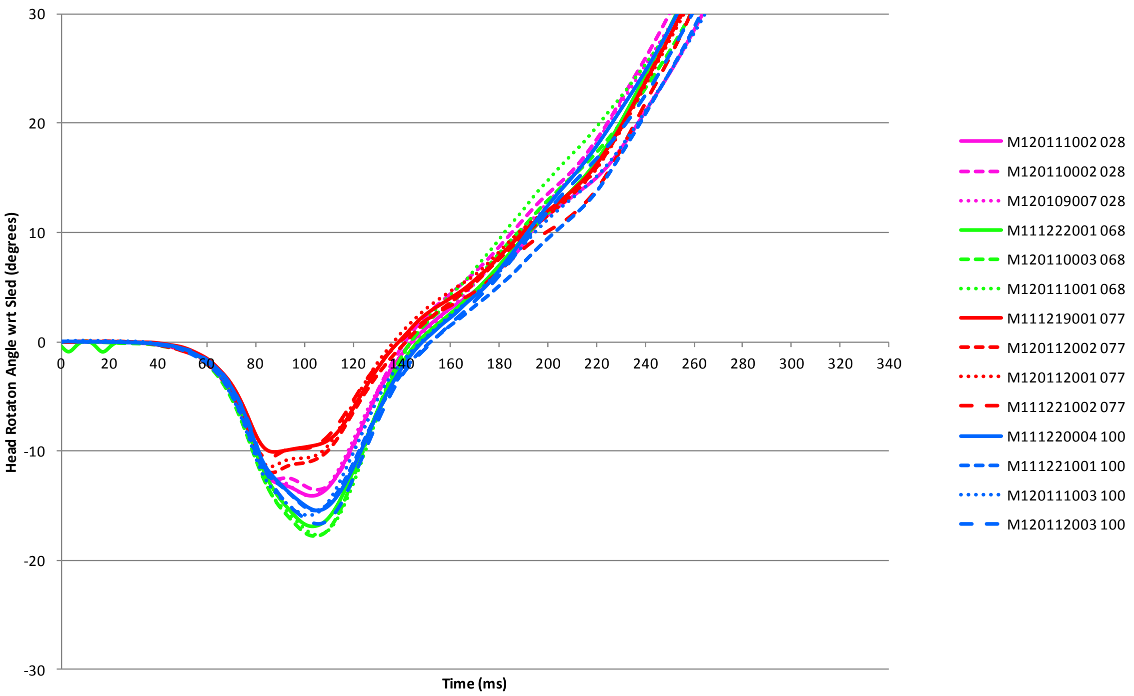


Figure 3-11: Head angle relative to the sled

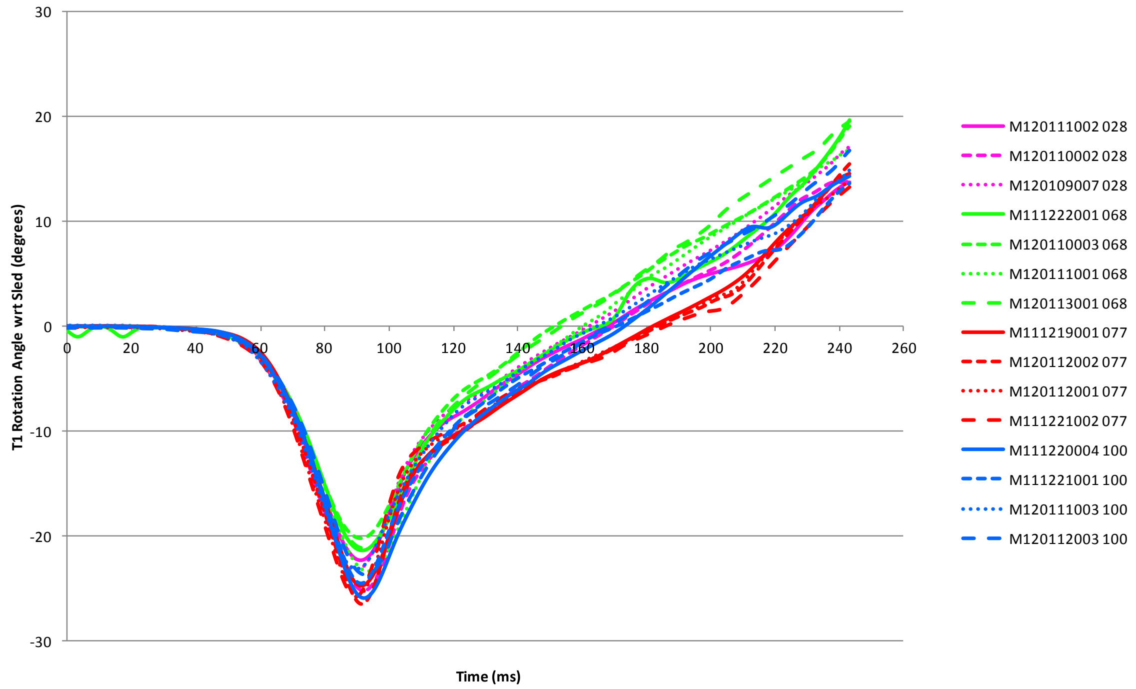


Figure 3-12: T1 angle relative to the sled

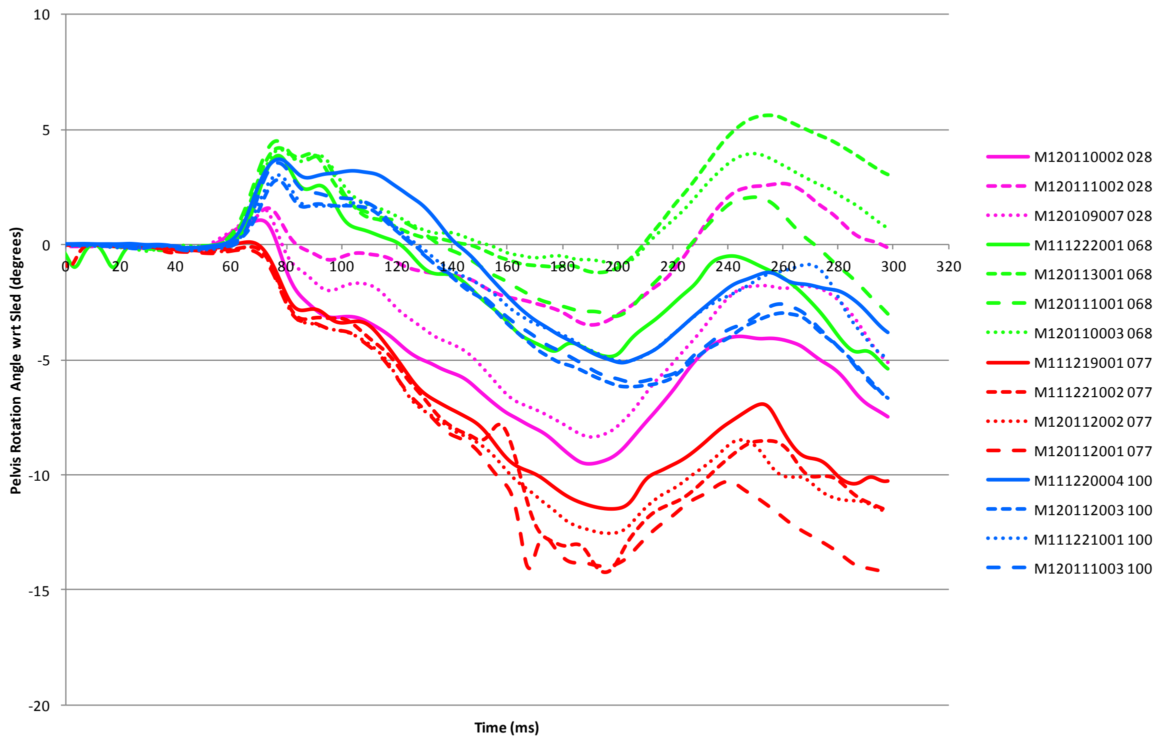


Figure 3-13: Pelvis angle relative to the sled

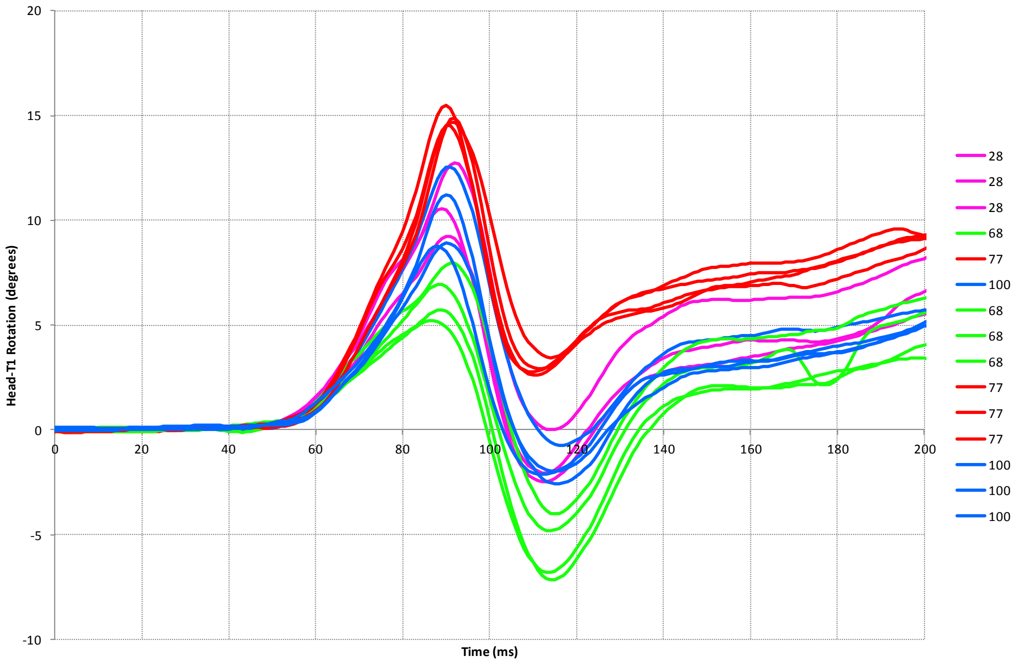


Figure 3-14: Head angle relative to T1 (positive is flexion)

Figure 3-15 and Figure 3-16 show the vertical displacement of the OC and T1 pins respectively. The peak z-axis displacement of the OC and T1 pins for dummies 068 and 077 just prior to head contact, at peak head restraint contact, and at peak upper neck extension moment, are shown in Table 3-1 (NB: negative displacements are vertically upwards compared to the initial position of the dummy). Up to about 120 ms, the upward Z-axis displacement is due to 'ramping-up' of the dummy. After about 120 ms, most of the change in Z-axis displacement is due to the dummy adopting a more upright posture during rebound.

Table 3-1: Z-axis OC and T1 displacements

	Dummy 077 OC deflection (mm)	Dummy 068 OC deflection (mm)	Dummy 077 T1 deflection (mm)	Dummy 068 T1 deflection (mm)
70 ms (just before head contact)	0	-8	-1	-6
90 ms (peak head restraint contact)	4	-10	-1	-14 to -18
110 ms (peak upper neck extension moment)	-7	-25 to -30	-9	-28 to -32

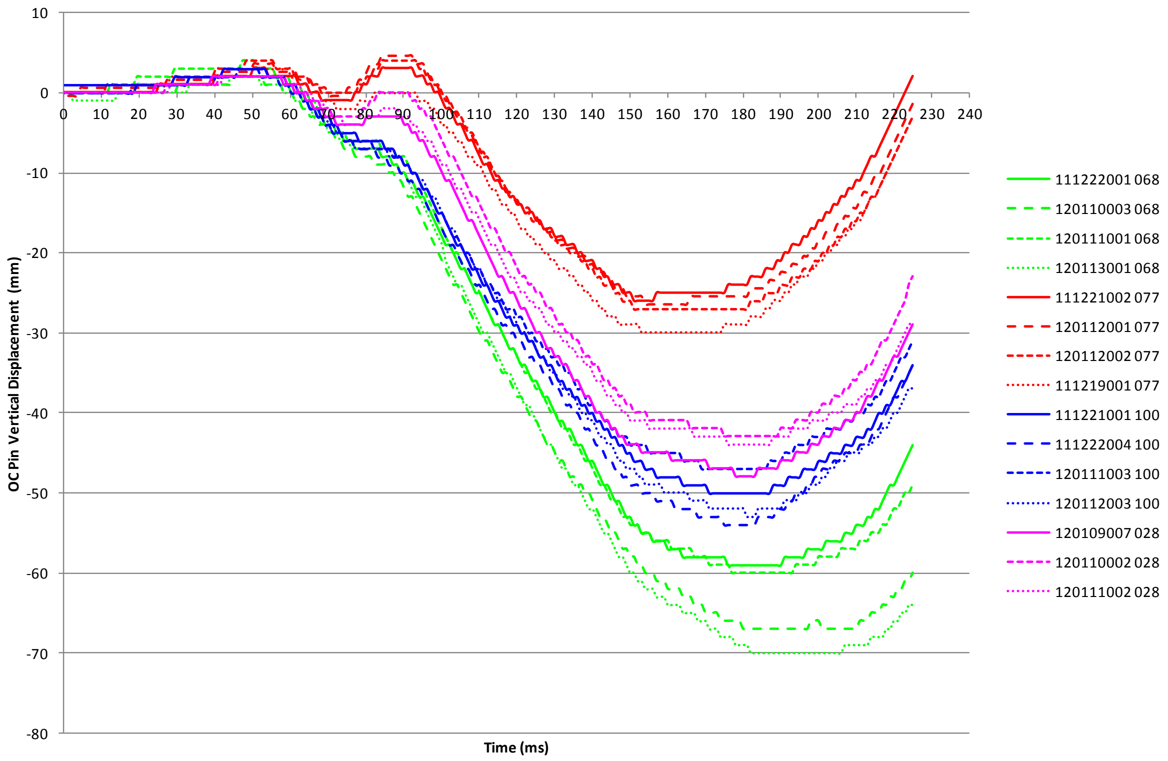


Figure 3-15: OC Z-axis displacement

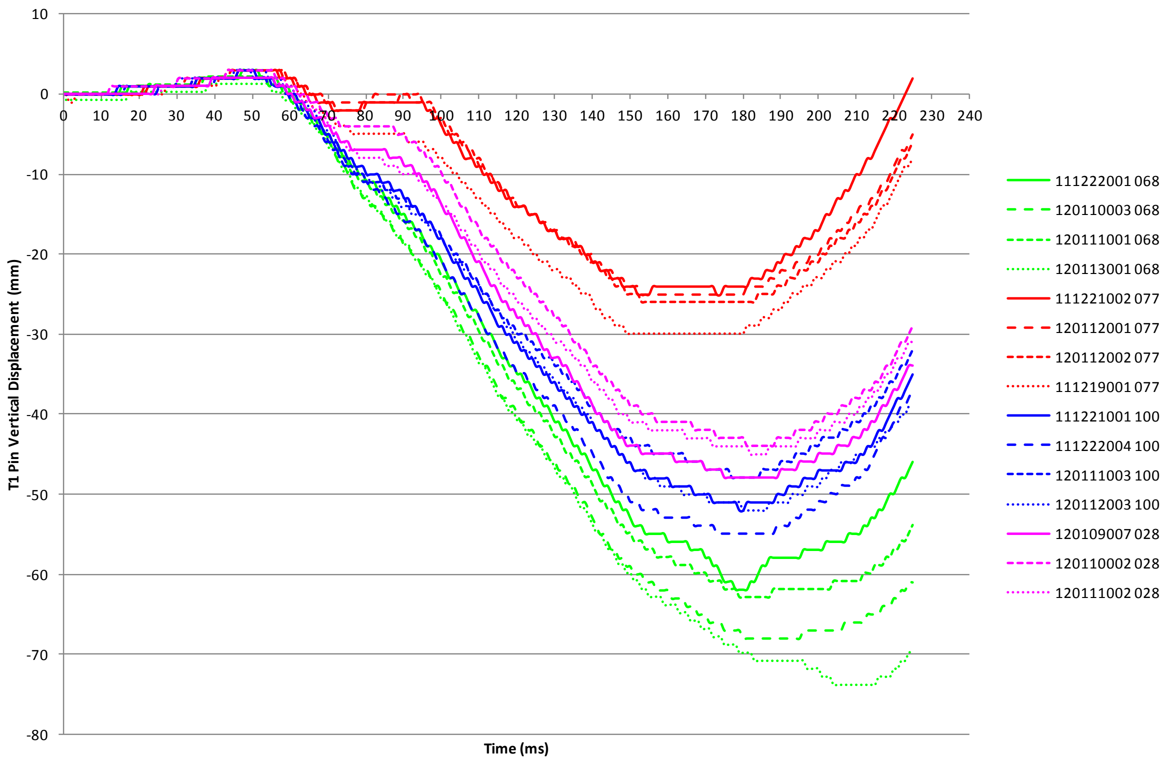


Figure 3-16: T1 Z-axis displacement

Ramping-up is due to a combination of global motion of the dummy and, when observed at the T1 or OC, straightening of the spine of the dummy. A similar ramping-up response has been reported in volunteer and PMHS tests. The ramping-up response of the BioRID dummy has been reported to be lower than the mean of human subject responses in several biofidelity test conditions.

The marker tracking data show that the 'ramping-up' response of the four dummies, i.e. the upward displacement of a seat occupant along the seat back during a rear impact, was markedly different. Dummy 077 shows very little ramping-up behaviour (less than 10 mm at T1 by the time of peak upper neck extension moment), while dummy 068 shows much greater ramping-up response (approximately 30 mm at the T1 by the time of peak upper neck extension moment). Variation in ramping-up response would be expected to affect spine interaction with the seat and head interaction with the head restraint, and therefore would be likely to affect the measured neck loads.

Finally, the displacement of the T1 pin relative to T1 in a seat-back co-ordinate system was calculated (see Figure 3-17). This kinematic parameter was found to be much more reproducible, with a CV of 11.8% for 15 tests with four dummies. Three tests show a somewhat greater relative displacement than the other 12 tests, and it is not clear from the marker tracking data why this is.

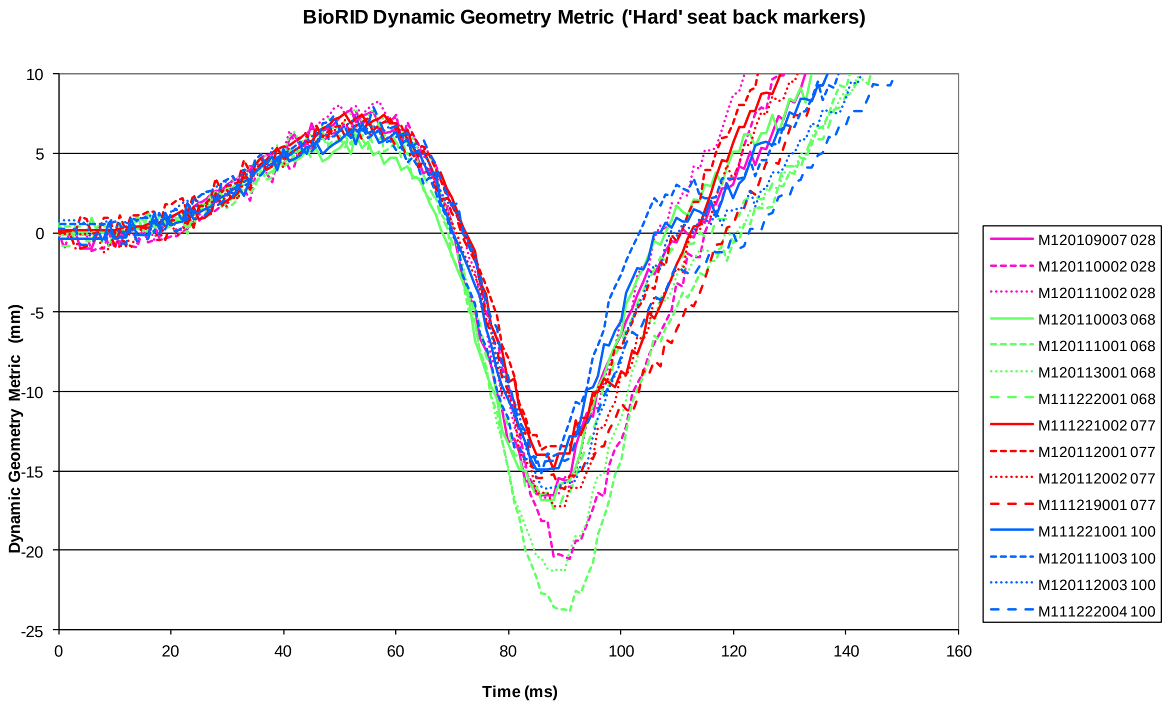


Figure 3-17: OC displacement relative to T1 in a seat-back co-ordinate system

3.1.6 Summary

The baseline tests demonstrated very good repeatability of the test condition, including pulse and seat response. Most dummy channels also showed good repeatability, but several channels showed poor reproducibility, notably:

- Pelvis Ax and Ay accelerations
- T1 and upper neck Fz forces
- Upper neck My moment

As noted in Section 3.1.3, the head restraint was permanently displaced rearward slightly in each test. Despite this, each dummy is clearly identifiable with a unique pelvis acceleration, upper and lower neck Fz, and upper neck My response. This indicates that the change in dummy posture that was required to maintain the BioRID target backset had a negligible effect on the dummy response across this test series. Other channels showed qualitatively reasonable or good reproducibility, particularly given the low measurement values in some channels.

3.2 Phase 2a: Dummy 068 with Modified Backset

Appendix D shows the results of two tests with dummy 068 with the backset modified as follows:

- Dummy seated as in baseline tests, but with no attempt to match the backset. This gave a backset of 95 mm *cf.* 75 mm in the baseline tests
- Dummy seated as above, but with head restraint moved 20 mm forward to restore the 75 mm backset from the baseline tests

These modifications had little effect on the pelvis or L1 responses. The T8, T1, C4 and head Ax responses after 80 ms were delayed about 10 ms in the test with a 95 mm backset, and the magnitude of C4 and head Ax responses was reduced when the head restraint was brought forward. Z-axis accelerations were similarly delayed with the larger backset.

T1 Fx, which had showed good consistency in all 20 baseline tests showed a delayed response (matching that of the accelerations) with the increased backset, and a markedly reduced peak shear force with the head restraint brought forward. This may indicate the importance of maintaining a neutral neck posture while achieving the target backset. A similar pattern was seen for T1 My, with the response curve delayed after 80 ms with the larger backset, and a reduced extension / increased flexion moment with the head restraint brought forward to restore the target backset.

T1 Fz was delayed with the head restraint brought forward, but the peak force was unchanged. In contrast, the peak force rose to the same level as dummy 077 in the test with the larger backset.

At the upper neck, the increased backset delayed the peak Fx response as was observed for the T1 Fx. However, moving the head restraint forward markedly *increased* the peak shear force at the upper neck Fx.

Upper neck Fz followed the same pattern as T Fz. Increasing the backset to 95 mm delayed and slightly reduced the peak neck extension moment, but moving the head restraint forward by 20 mm had no effect on this measurement compared with the baseline responses for this dummy.

3.2.1 Summary

These tests indicated that backset and dummy posture are important for T1 and upper neck Fz measurements, but the repeatability of these responses in the baseline tests indicates that these parameters are adequately controlled within the BioRID seating procedure for a given target backset. However, it also indicates that a consistent target backset would be very important and the repeatability and reproducibility of this measurement with the 3D H-point machine and HRMD has not been assessed in this test programme.

The results also indicate that significant changes in posture and backset had very little effect on the upper neck My extension moment.

3.3 Phase 2b: Dummy 068 with Raised H-point

As noted in Section 3.1.4, it is likely that there is some interaction between the pelvis and the reinforced recliner bar in the seat, and that this interaction is repeatable for each dummy and different between dummies. Two tests were undertaken with dummy 068 with the H-point raised approximately 30 mm by adding foam to the top surface of the seat base. The results of these tests are shown in Appendix E.

Figure 3-18 shows that with the H-point raised in this way, the pelvis X-axis acceleration was markedly reduced and occurred later. In fact, the magnitude is reduced almost to the same level as the L1 and T8 accelerations

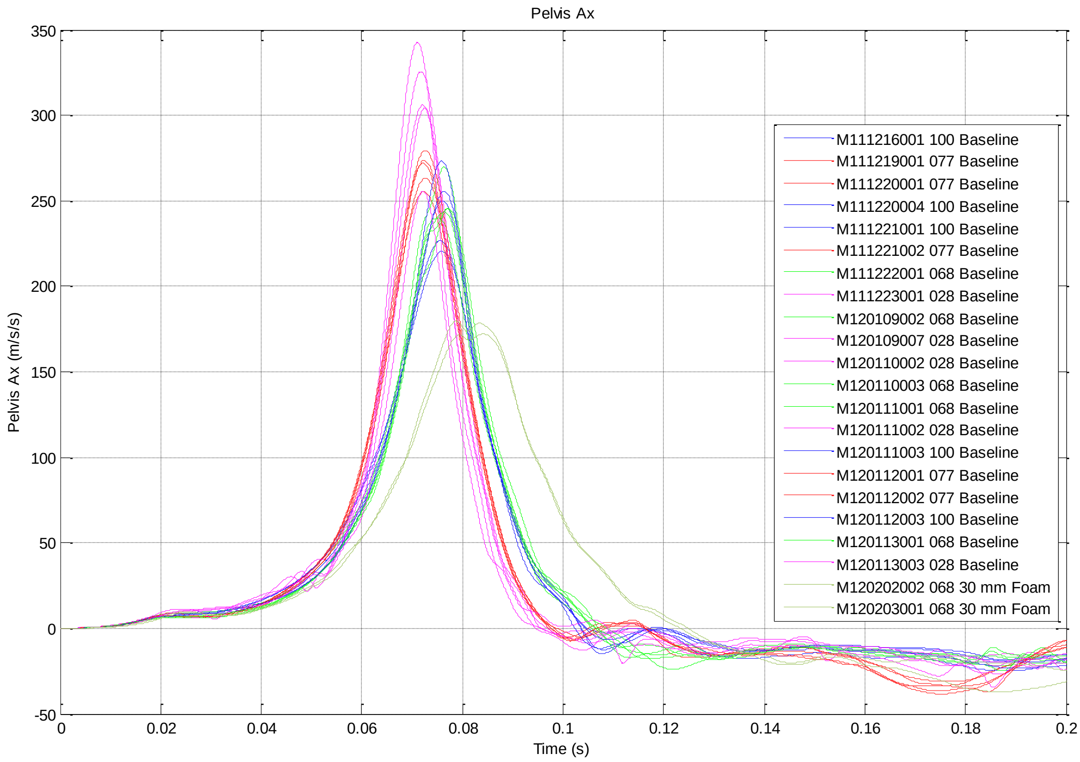


Figure 3-18: Pelvis Ax with H-point raised approximately 30 mm with foam on the seat base

This confirmed that in the baseline tests the pelvis of the dummies was interacting with the reinforcement around the recliner adjustment bar. The reinforcement was stiffer than the original recliner bar, which became increasingly deformed in pilot tests prior to the main test programme. It was considered that this would lead to a non-repeatable interface between the dummy and the seat back, which was undesirable for evaluating the repeatability and reproducibility of the dummy. Therefore, this part was reinforced to prevent deformation. It is likely that the stiffer contact this gives would exaggerate any differences between dummies that are related to interaction with the recliner bar compared with the original seat. However, other seats may have stiffer recliner bars or other parts in this region of the seat back, and an exaggerated interaction may help with identifying the source of any differences between dummies.

While the X-axis pelvis acceleration was reduced markedly by raising the H-point, the Z-axis acceleration was increased in the second peak at 90 ms. Although there was very little change in T1 X-axis acceleration, there was a marked effect on the magnitude and timing of T1 and upper neck forces and moments. The change in phase with increased H-point height, which was not observed in the baseline tests, suggests that any variation in H-point height between the four baseline dummies (see Section 3.1.3) had little observable effect on the measurements in terms of altered interaction with the upper seat back and head restraint. However, small changes in H-point height could have a large effect on pelvis interaction with any hard structures in the lower seat back because of the non-smooth (and non-biofidelic) profile of the rear or the pelvis. It is therefore important that this parameter is well controlled by the seating procedure and the pelvis geometry.

3.3.1 Summary

The tests with the H-point raised by approximately 30 mm demonstrated the effect of pelvis interaction with the reinforced recliner bar, and suggest that the reinforcement will exaggerate any differences between dummies caused by this interaction compared with the OEM seat. However, it was felt that the reinforcement was necessary to achieve a repeatable test and any exaggeration of dummy differences would help to identify the cause of the differences. The large effect of the H-point height change on the phasing of the neck responses suggests that the relatively small H-point height differences observed between dummies, which may have been partially due to play in the H-point tool, was unlikely to have had a large effect on the results.

3.4 Phase 3: Baseline Tests with Dummy 006 and 007

Following presentation of the baseline tests with dummies 028, 068, 077 and 100 at a TEG meeting, PDB made dummies 006 and 007 available for testing on the TRL seat. Both of these dummies had been identified as having outlying performance for upper neck My and T1 Fz in tests published by PDB in 2009 and had shown different performance in tests at OSRP in September 2011. Since these test programmes, both dummies had been refurbished by Humanetics, Heidelberg, with the following modifications:

- All cervical, thoracic and lumbar bumpers were replaced with bumpers from the same batch (six different specifications of bumper in total)
- All vertebrae were checked and replaced if the holes for the spine pins did not meet the tolerance defined by the Informal Group for the GTR BioRID specification

- All spine pins were replaced with the stainless steel pins defined by the Informal Group for the GTR BioRID specification

The results of testing with these updated dummies are shown in Appendix F. Figure 3-19 shows the upper neck My from this series of tests, compared with the baseline tests with dummies 028, 068, 077 and 100.

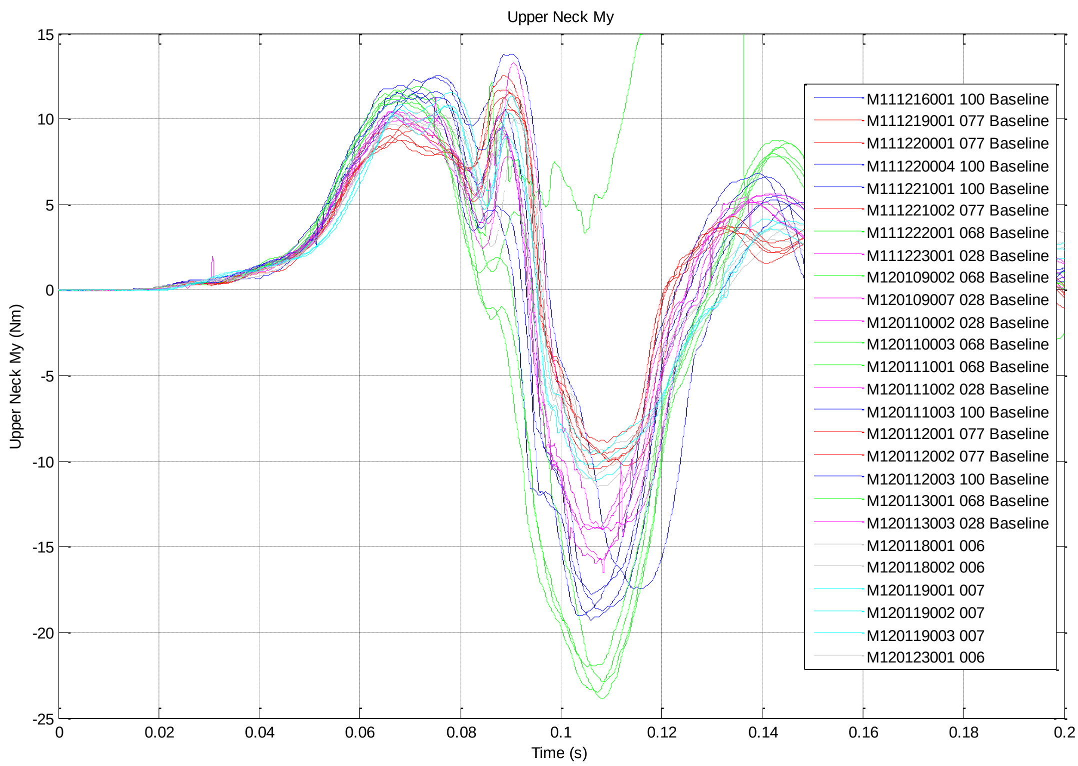


Figure 3-19: Upper neck My for refurbished dummies 006 and 007 compared with baseline tests with dummies 028, 068, 077 and 100

It can be seen that the response of the two PDB dummies is now very similar, especially for the upper neck moment response, which is very similar to dummy 077. The other neck forces and moments were generally towards the high end of the range measured with the other dummies, or higher, similar to the results for dummy 077. Pelvis acceleration was also similar to dummy 077 in both the X- and Z-axes.

The certification data in Appendix O.2 (certification test with head restraint) shows that the refurbished 006 and 007 have very similar total head rotation and upper neck My responses, and the pre-refurbishment certification data showed different responses for the two dummies. Unfortunately, at the time of writing certification data for the no-head-restraint, jacket and pelvis tests was not available for dummy 006 and 007.

3.4.1 Summary

The refurbishment process appears to have greatly reduced the differences between dummy 006 and dummy 007 compared to previous test series. However, it is not possible to be certain about the extent of change because of the different seat and pulse used in this test series. The certification data from the with-head-restraint test shows that the upper neck My and total head rotation of the two dummies are much more consistent after refurbishment, which indicates a correlation between these certification results and seat test results. Currently, there are no proposed certification requirements for the test with a head restraint, but it would seem to be important that these are developed.

3.5 Phase 4: Dummy 068 and 077 with Parts Swapped

An extensive series of tests was then undertaken using the two most outlying dummies from the first set of 20 baseline tests, i.e. dummies 068 and 077. The following types of test were conducted:

- Dummy 068 with the spine from dummy 077 / dummy 077 with the spine from dummy 068 (for full results see Appendix G)
- Dummy 068 with the pelvis from dummy 077 / dummy 077 with the pelvis from dummy 068 (for full results see Appendix H)
- Dummy 068 with the pelvis and spine from dummy 077 / dummy 077 with the pelvis and spine from dummy 068 (for some tests the jacket and legs were also swapped between dummies (for full results see Appendix I)

3.5.1 Dummy 068 and 077 with Spine Swapped

Changing the spine between the dummies had a surprisingly small effect on the responses. Very little effect was seen for T1 and upper neck Fx, which were similar on the two dummies in baseline tests anyway. T1 and upper neck Fz were hardly changed for dummy 077 with the spine from dummy 068, but dummy 068 with the 077 spine showed a marked increase in the peak value for both measurements. This may be related to a change in the pelvis Az at the same time (90 ms) as shown in Figure 3-20. The dummy 068 with pelvis 077 neck force and moment responses were variable, which may correlate with the observed difference in pelvis Az response for these two tests. No difference in pelvis Ax response was observed with the spines swapped (Figure 3-21).

The upper neck My response with swapped spines is shown in Figure 3-22. The magnitude of the upper neck My extension is very similar following the spine swaps, but the second peak flexion response is not affected to such a large extent. This seems to indicate that the spine response is quite influential in the extension moment response, but has a smaller influence on the second peak of the flexion response. Prior to head contact with the head restraint, the upper neck flexion moment is very similar for the dummies with swapped spines, whereas it was quite different in the baseline tests. This suggests that improvements to the spine could reduce the differences between the dummies, but not eliminate them entirely.

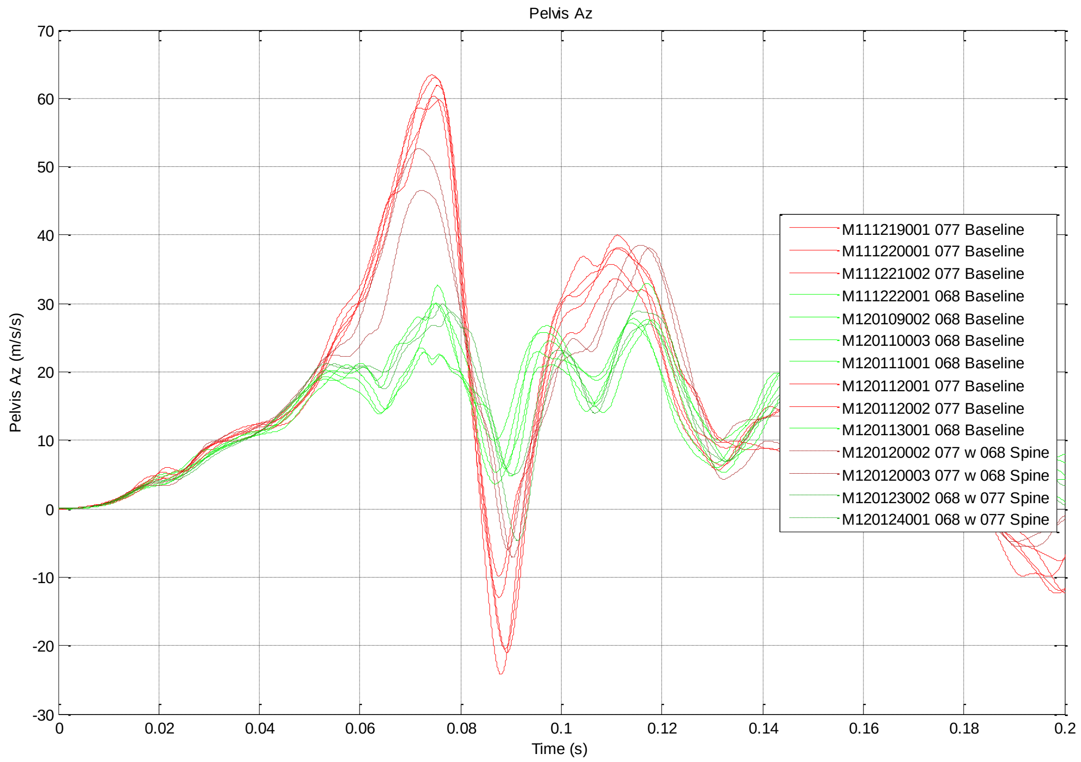


Figure 3-20: Pelvis Z-axis acceleration for dummies 068 and 077 with swapped spine parts, compared with baseline tests

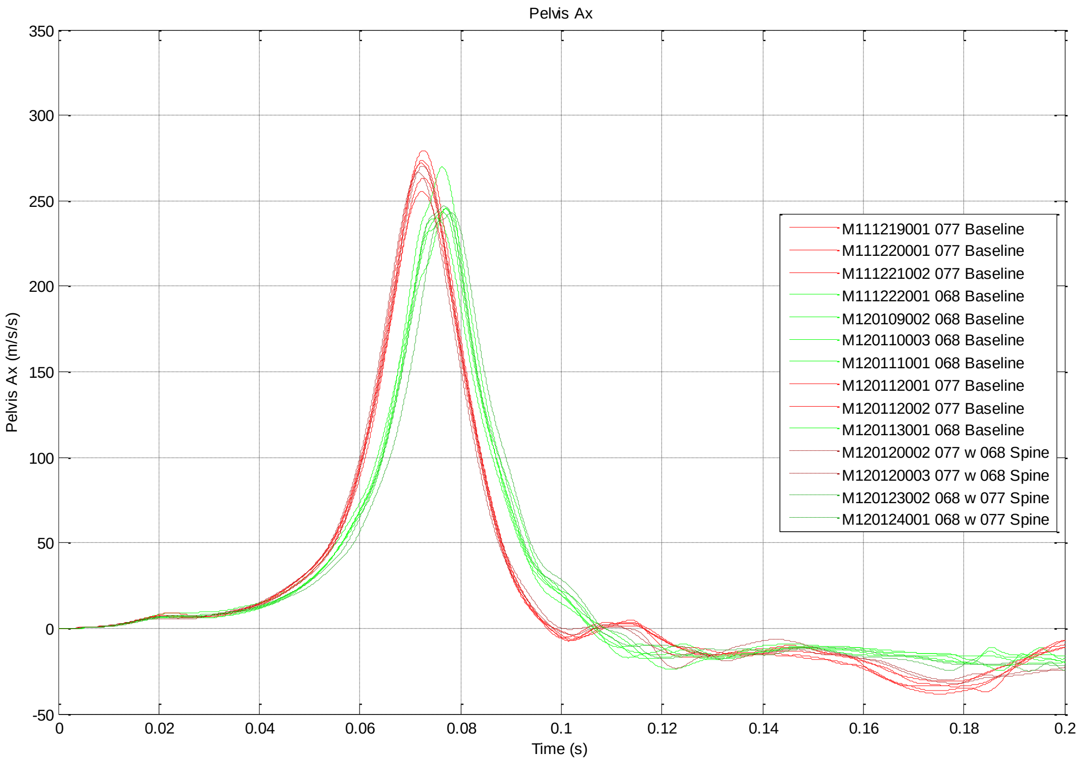


Figure 3-21: Pelvis X-axis acceleration for dummies 068 and 077 with swapped spine parts, compared with baseline tests

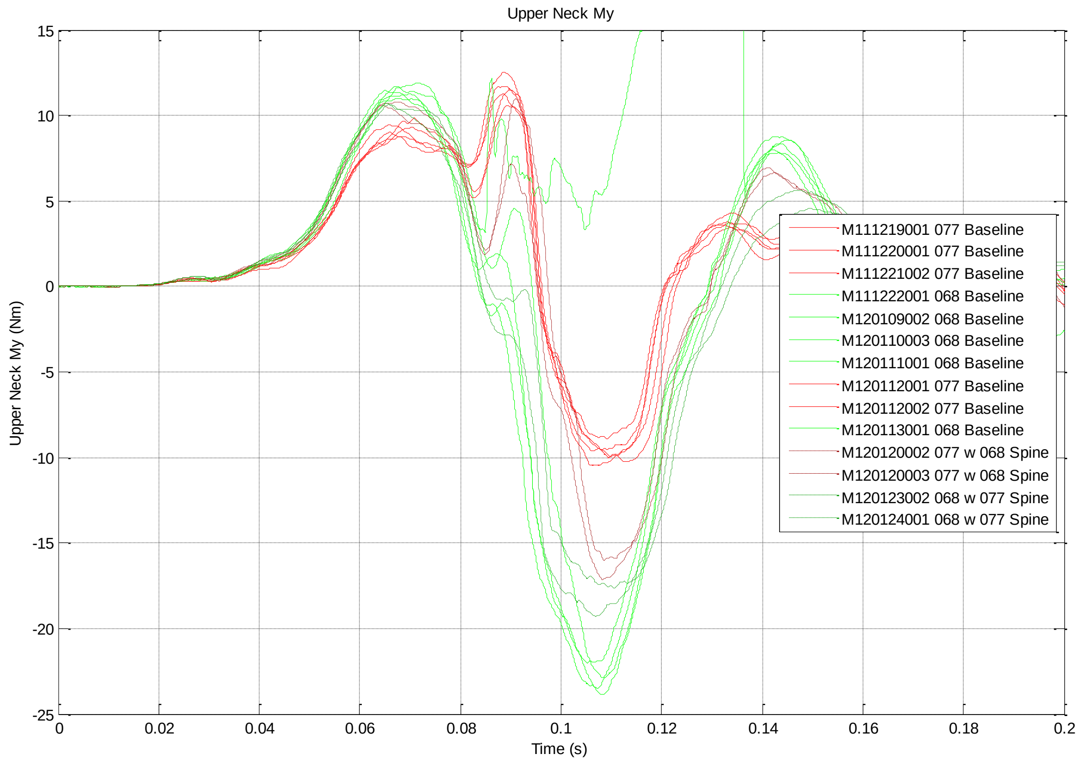


Figure 3-22: Upper neck My for dummies 068 and 077 with swapped spine parts, compared with baseline tests

3.5.2 Dummy 068 and 077 with Pelvis Swapped

Pelvis X-axis accelerations swapped between the dummies when the pelvis was swapped, in terms of both the timing and magnitude of the response (see Figure 3-23). Together with the absence of a change in response when the whole spine was swapped, this suggests that the performance of pelvis itself is primarily responsible for controlling X-axis pelvis response. This response is not assessed by the current certification procedures for the dummy. Again, this effect is likely to be somewhat exaggerated in the TRL seat, but may be expected to occur to some extent in any seat where the pelvis can interact with structures in the seat back.

Figure 3-24 shows the pelvis Z-axis acceleration with the pelvis swapped between dummies. In this case the acceleration response is between the response of the dummies in the baseline tests. This indicates that the pelvis itself is an important factor in controlling the Z-axis pelvis response, but is not the only dummy factor affecting this response. The T1 and upper neck Fz swapped with the change of pelvis, which may indicate that the pelvis response (in X and Z axes) is very influential on the Z-axis neck response.

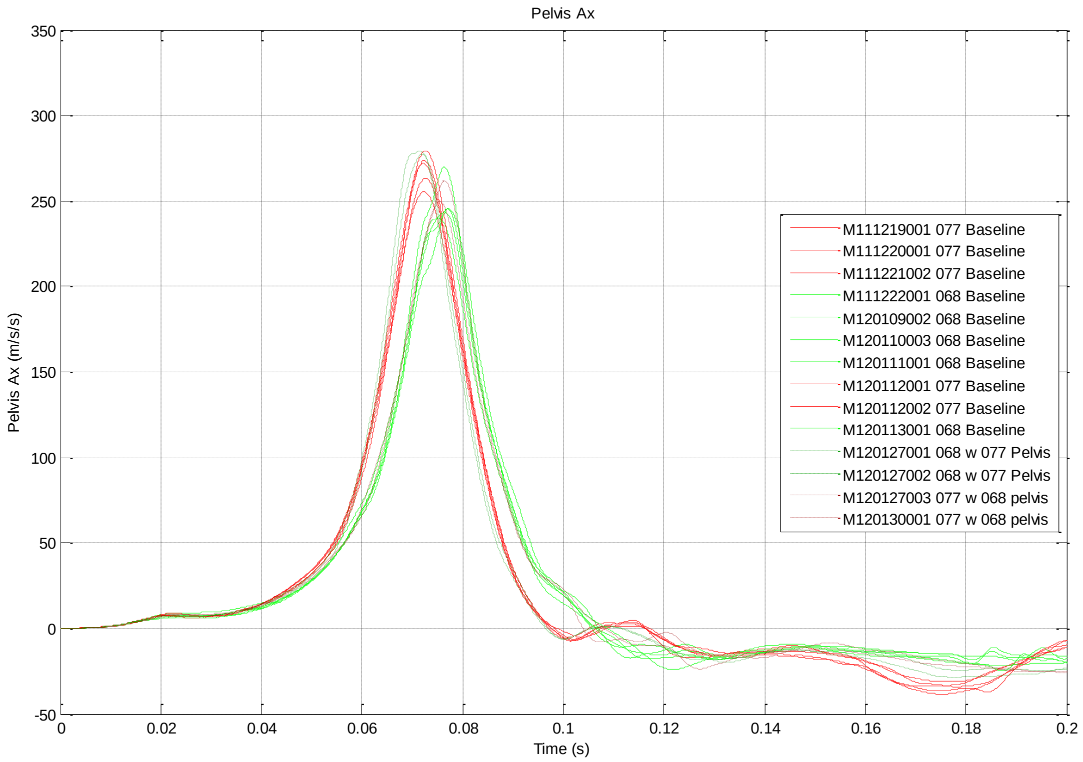


Figure 3-23: Pelvis X-axis acceleration for dummies 068 and 077 with swapped pelvis parts, compared with baseline tests

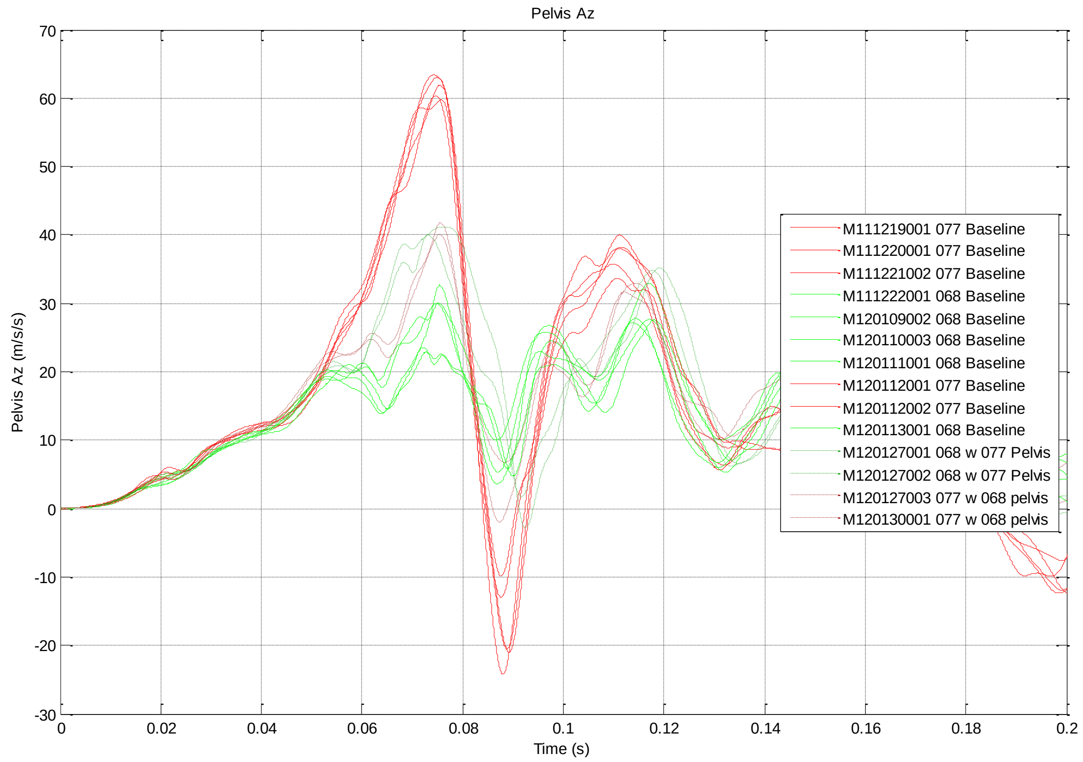


Figure 3-24: Pelvis Z-axis acceleration for dummies 068 and 077 with swapped pelvis parts, compared with baseline tests

Surprisingly, the T1 X-axis acceleration swapped exactly with the change of pelvis, i.e. dummy 077 with the pelvis from dummy 068 had exactly the same T1 Ax response as the baseline dummy 068 tests, and vice versa. This may indicate a dependency of the T1 Ax response on pelvis flesh stiffness.

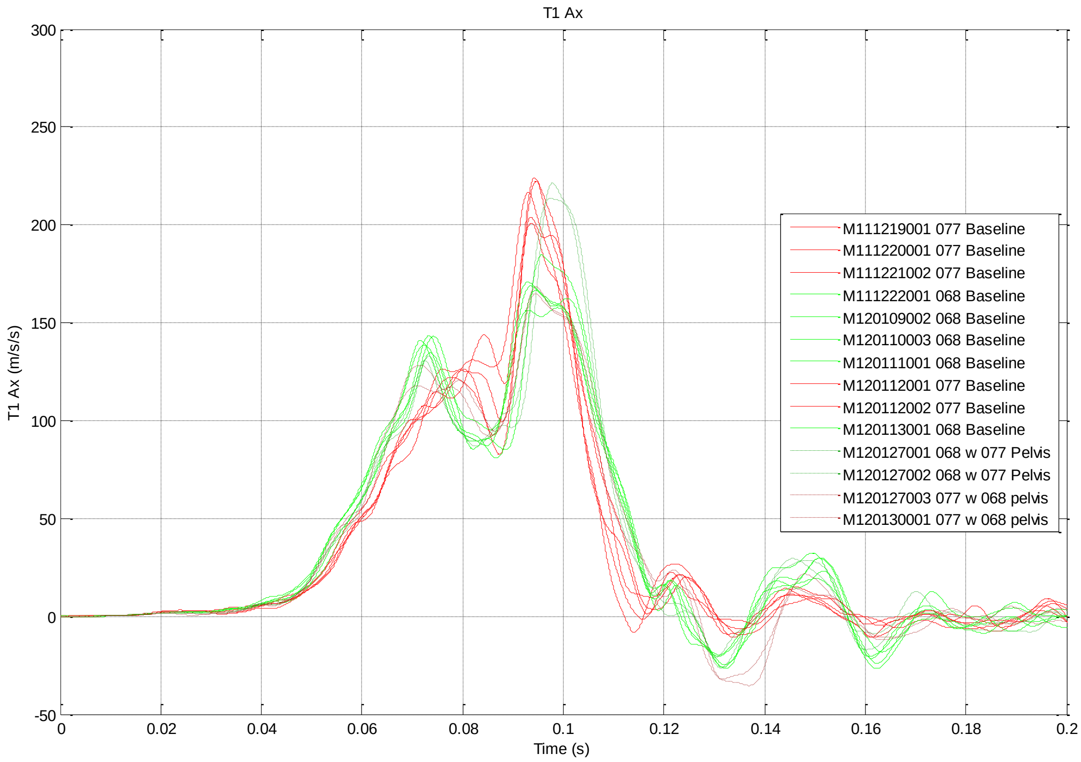


Figure 3-25: T1 X-axis acceleration for dummies 068 and 077 with swapped pelvis parts, compared with baseline tests

Finally, Figure 3-26 shows the upper neck My response with the swapped pelvis parts. The magnitude of upper neck My is very similar for the two dummies once the pelvis parts have been swapped (-16 to -19 Nm, compared with -9 to -23 Nm for the baseline tests). It should be noted that the pelvis parts on dummy 068 and 077 have quite different stiffness (see Appendix O.4). Therefore, it may be expected that controlling the stiffness of the pelvis, e.g. to a stiffness mid-way between dummy 068 and dummy 077, would not fully control address the variation in upper neck My. In fact, the implication is that the effect of harmonising pelvis response would be to half the variation in upper neck My extension moment. It would also appear that a similar improvement would occur for the second flexion peak at 90 ms.

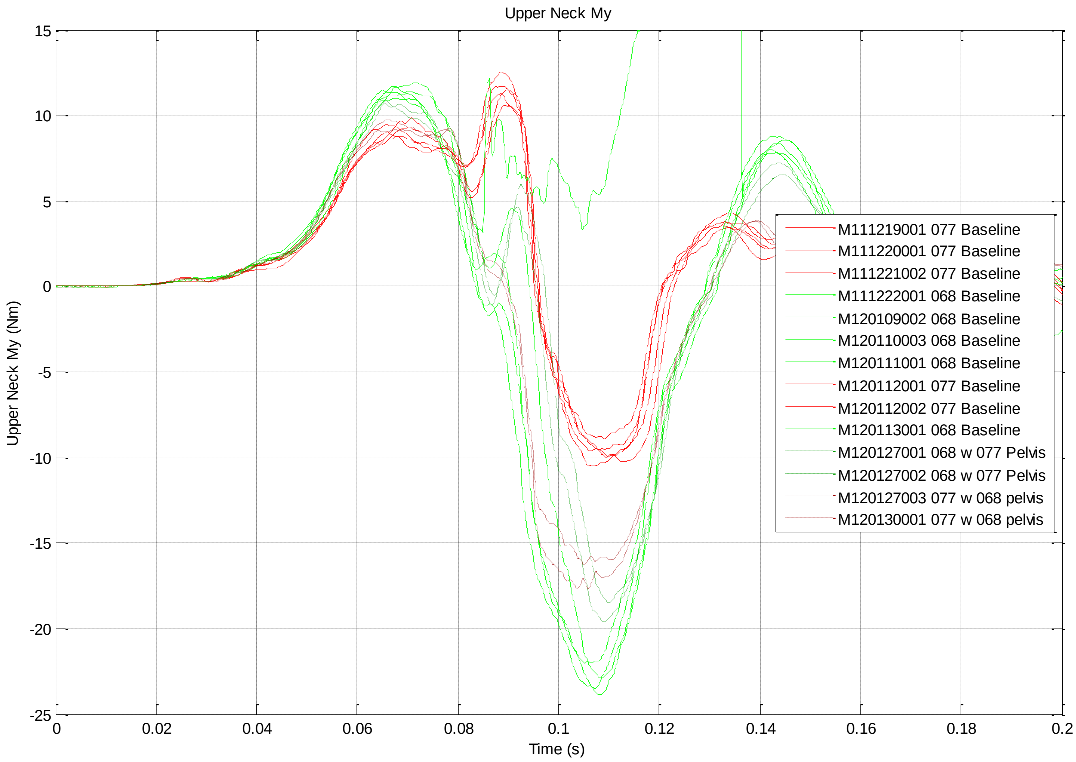


Figure 3-26: Upper neck Y-axis moment for dummies 068 and 077 with swapped pelvis parts, compared with baseline tests

3.5.3 Summary

The results of the tests with the pelvis or spine swapped between dummies 068 and 077 were initially somewhat unexpected. It would appear that for those measurements where differences between dummies were observed in the baseline tests, the pelvis was more influential on the overall response of the dummy than the spine. However, the performance of the spine is at least partially controlled in the current certification procedure, whereas the stiffness of the pelvis is currently uncontrolled and was quite different for these dummies as shown in the certification-type pelvis impact tests subsequently undertaken with these dummy parts.

Therefore it is recommended that improved control of pelvis stiffness is introduced. In order to investigate further the differences in spine stiffness between dummy 068 and 077 (as well as for other dummies used in this test programme), a quasi-static spine stiffness check was suggested and has been implemented by Humanetics. This test quantifies the rotation of the spine at different vertebral levels under fixed loading conditions, in both flexion and extension. This may help to identify differences between the dummies that are not exposed by the current sled-based certification test, which does not exercise the lower thoracic and lumbar spine very efficiently. The quasi-static spine stiffness tests are still being conducted at the time of writing and the results will be reported to the TEG by Humanetics.

3.6 Phase 5: Dummy 068 and 077 Rebuilt

Two tests were undertaken with dummy 068 and dummy 077 rebuilt to their original configuration (see Appendix J), i.e. with dummy 068 containing only parts from dummy 068. These were undertaken in order to check that the performance of each dummy returned to its original performance, which was necessary as a check that no significant change in seat or dummy performance had occurred during the large number of tests that had been undertaken with the dummy. In one test with dummy 077, the head restraint started to yield, the effect of which can clearly be seen in the time shift for the neck forces and moments, and a significant reduction in the C4 and head Ax measurements. The head restraint was replaced with a new one, and the test repeated, so five tests were performed in total for this Phase.

Pelvis X-axis acceleration for each rebuilt dummy was within the range of the baseline tests (Figure 3-27), and this was generally the case for the X-axis accelerations. Pelvis Z-axis acceleration (Figure 3-28) was also essentially identical for the first (positive) peak, and the second (negative) peak for dummy 068; dummy 077 had a slightly reduced second peak response compared with the baseline tests. The other Z-axis accelerations were also a good match for the baseline tests. There was some variation in T1 forces and moments, and for upper neck Fz for individual tests, as shown in the Appendix. T1 and upper neck Fz seem to have increased for the second test with dummy 068, despite the Z-axis accelerations at all levels being very comparable to the baseline tests. This seems to be related to a very late head restraint contact, although the dummy and seat CMM data show that the dummy and head restraint positions were very similar to previous tests.

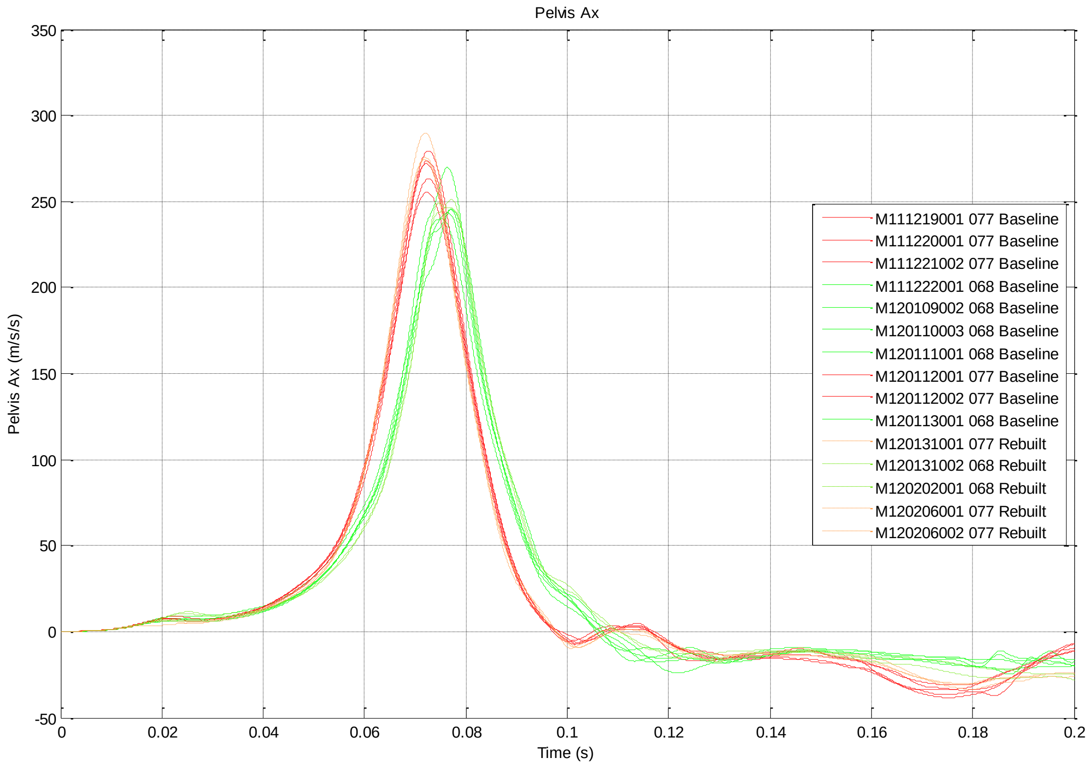


Figure 3-27: Pelvis X-axis acceleration for dummies 068 and 077 rebuilt to their original configuration

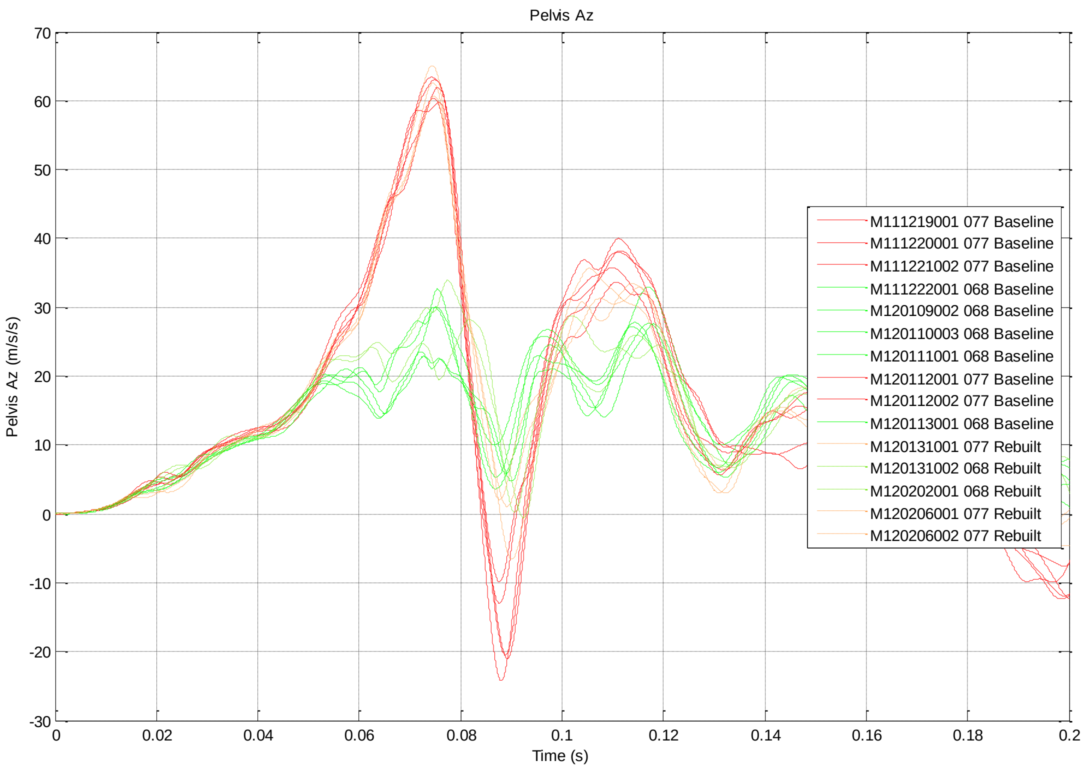


Figure 3-28: Pelvis Z-axis acceleration for dummies 068 and 077 rebuilt to their original configuration

Upper neck My is shown in Figure 3-29. It can be seen that the responses prior to head restraint contact are a very close match with the baseline tests, but that there is some variation from the baseline tests during head restraint contact. In particular, the magnitude of upper neck extension moment for dummy 068 is slightly reduced (20 Nm compared with 22-24 Nm in the baseline tests).

3.6.1 Summary

Overall, dummies 068 and 077 returned close to their original performance in the baseline tests when they had been rebuilt to their original configuration. X- and Z-axis accelerations in particular were comparable to the baseline tests. Z-axis forces at the T1 and upper neck level were somewhat higher for one test with dummy 068, even though the Z-axis accelerations for this dummy were very similar to the baseline test results. The difference seems to be due to a very late contact with the head restraint, although the reason for this is not certain. The head restraint yielded in the next test (with dummy 077), so it may be that the head restraint was already damaged in this test and moved from its initial position during the initial acceleration of the sled, giving a larger backset.

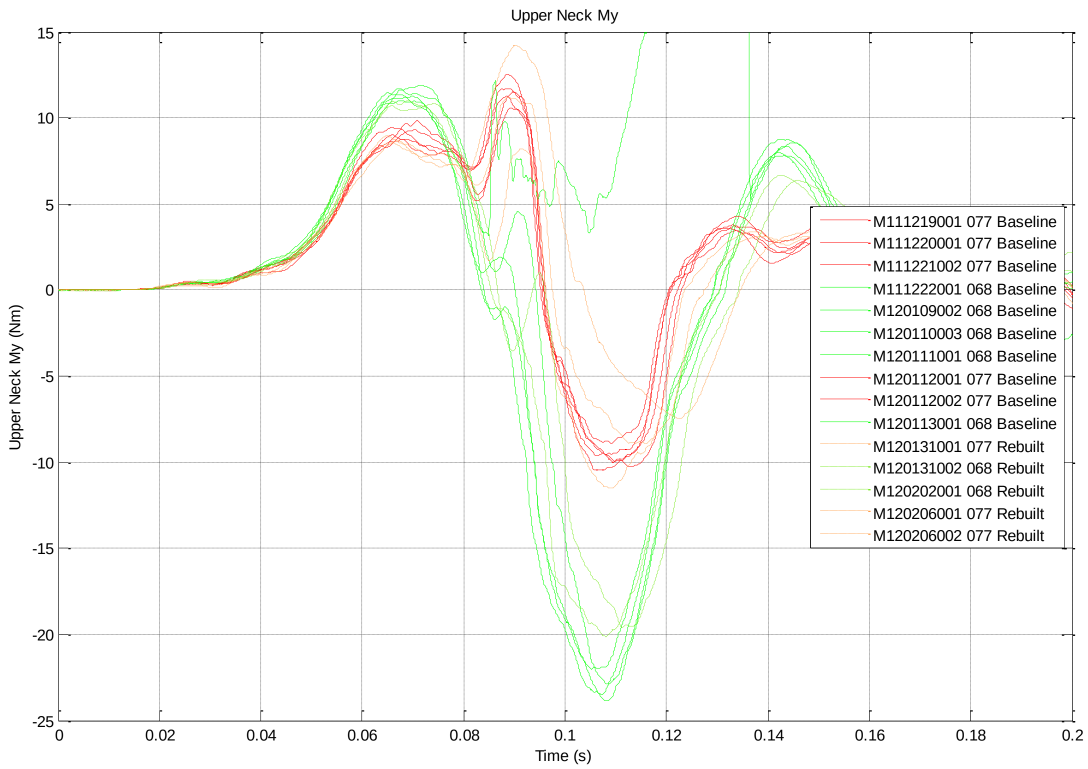


Figure 3-29: Upper neck Y-axis moment for dummies 068 and 077 rebuilt to their original configuration

3.7 Phase 6: Dummy 006 and 007 with Dummy 068 or 077 Pelvis

Four tests were undertaken with dummy 006, fitted with the pelvis from dummy 068 or 077, and dummy 007, also fitted with the pelvis from dummy 068 or 077. In Phase 4 of the test programme (Section 3.5), it was shown that swapping the pelvis had a large influence on the response of the dummy, even at the upper neck. The results of using these pelvises with dummies 006 and 007 are shown in detail in Appendix K.

Dummy 006 with the harder pelvis (from dummy 077) had an increased pelvis Az response, and dummy 007 with the softer pelvis (from dummy 068) had a reduced pelvis Az response, very similar to the change observed when fitting this pelvis to dummy 077 (see Figure 3-30). However, the converse was not true: fitting pelvis 077 to dummy 007 and pelvis 068 to dummy 006 did not notably affect the response. However, this may be related to the seat back response, which was affected by the pelvis used. When the 077 (harder) pelvis was fitted, both tests with 006 and 007 showed an increased seat back rotation angle (by 0.1° to 0.2°); with the softer pelvis from dummy 068 was fitted, the seat back response was smaller, by a similar amount.

As shown in Figure 3-31, the upper neck My was relatively little effected by the change in pelvises, compared with the effect that swapping the same pelvises had on dummies 068 and 077.

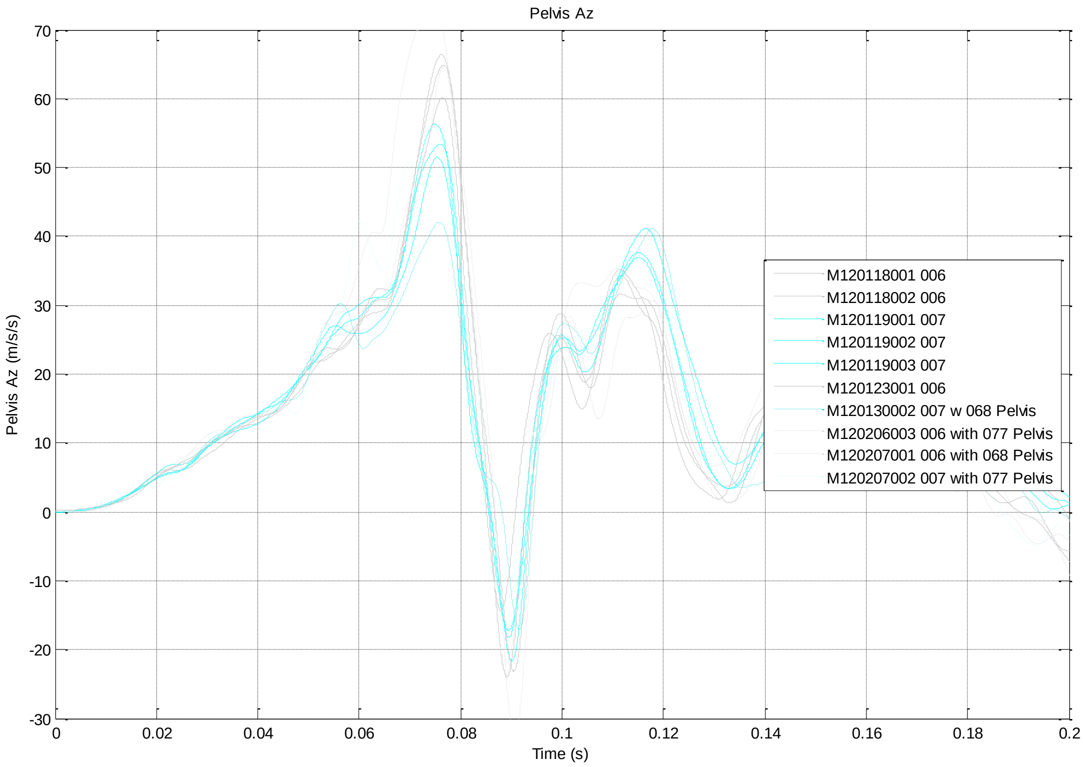


Figure 3-30: Pelvis Z-axis acceleration for dummies 006 and 007, with pelvises from dummies 068 and 077

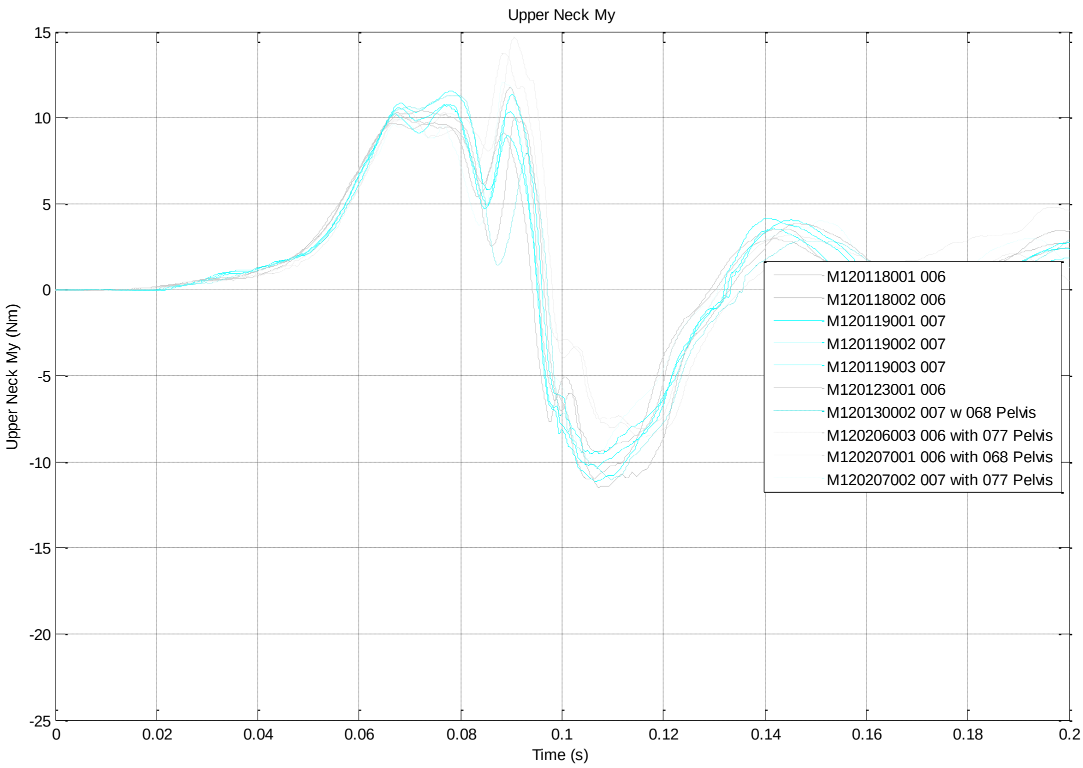


Figure 3-31: Upper neck Y-axis moment for dummies 006 and 007, with pelvises from dummies 068 and 077

3.7.1 Summary

At first sight, the results from these tests are somewhat confusing. Certainly, using pelvis 068 and 077 with dummies 006 and 007 had much less effect on the dummy responses than swapping the same pelvises was shown to have on dummy 068 and 077 in Section 3.5. However, the results may suggest that a number of effects are occurring in parallel, which would make it difficult to be precise about the magnitude of effect with any one dummy. For example, as will be shown in Section 3.10, refurbished dummies 006 and 007 had much softer lumbar bumpers than refurbished dummies 068 and 077. It is not known how stiff the bumpers installed in dummies 068 and 077 were for baseline tests, but it is known that the bumpers get stiffer over time. If the bumpers in dummies 006 and 007 were softer than the baseline 068 and 077 dummies, this may indicate that harder bumpers increase the transfer of pelvis acceleration variations caused by variations in pelvis stiffness. Given that the stiffness of the bumpers in the baseline dummies was not known (either at installation, or how much they had stiffened over time), this is speculative. However, it was shown in Section 3.1.5 that the pelvis rotation of dummies 068 and 077 was very different, with positive rotation for 068 and negative rotation for 077. That the rotations were different in sign is likely to have been due to a different interaction with the lower part of the seat back, but the magnitude of the difference could well be influenced by the stiffness of the lower spine bumpers. This indicates that control of bumper stiffness even at the lower spine may be important, although there is very little control of these bumpers in the certification tests.

3.8 Phase 7: Dummy 077 with Replacement Upper Rear Thoracic Bumpers

During the tests with the baseline dummies it was noted that dummy 077 had narrower bumpers at the upper two rear thoracic spine positions (T2 and T3). These were used to tune the ‘Pot C’ response in the with head restraint certification test. One test was run with these two bumpers replaced by standard thickness bumpers. These tests are shown in Appendix L. The dummy was also re-certified with the two new bumpers, which caused the dummy to fail the Pot C requirement (see Appendix O).

The change of these two bumpers had a surprisingly large effect on pelvis Z-axis acceleration, particularly the second (negative) peak response, which was much closer to the dummy 068 response in the baseline tests than the dummy 077 response (Figure 3-32). T1 (Figure 3-33) and upper neck Fz were also reduced compared with the baseline responses, whereas T1 Fx and My, plus upper neck Fx were comparable to the baseline tests. Upper neck My (Figure 3-34). There was no effect on upper neck My prior to head restraint contact, but both the second peak (flexion) and third peak (extension) were shifted markedly towards the response of dummy 068.

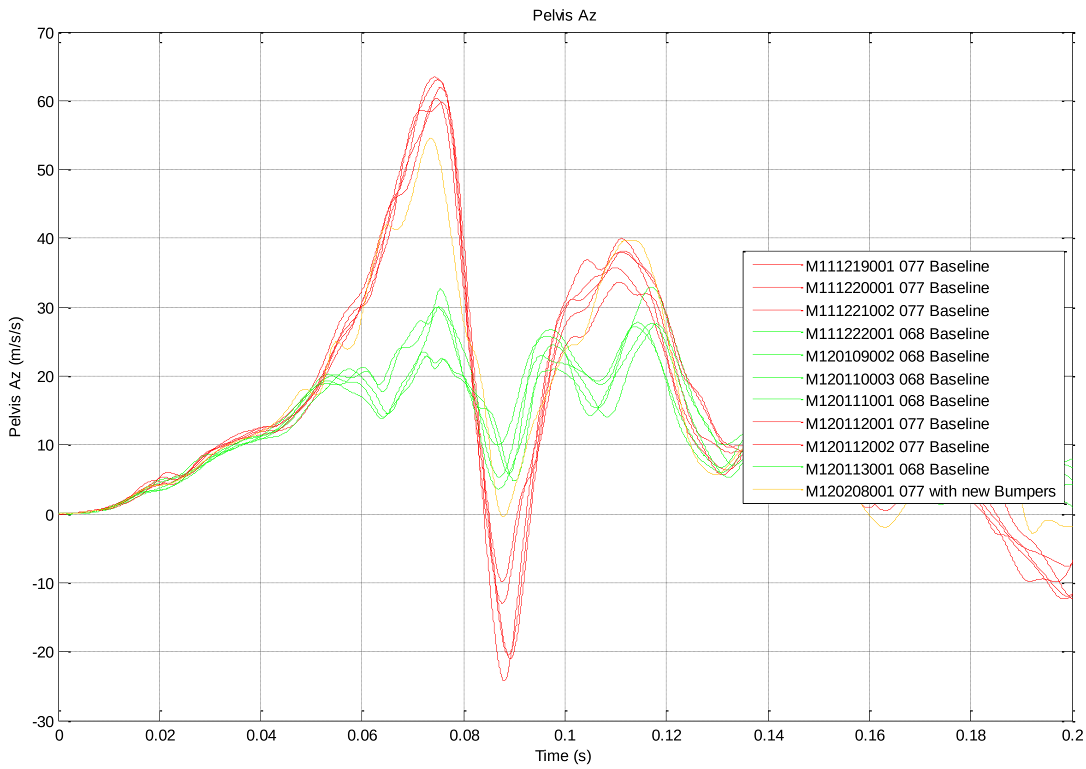


Figure 3-32: Pelvis Z-axis acceleration for dummy 077 with standard thickness T2 and T3 rear bumpers

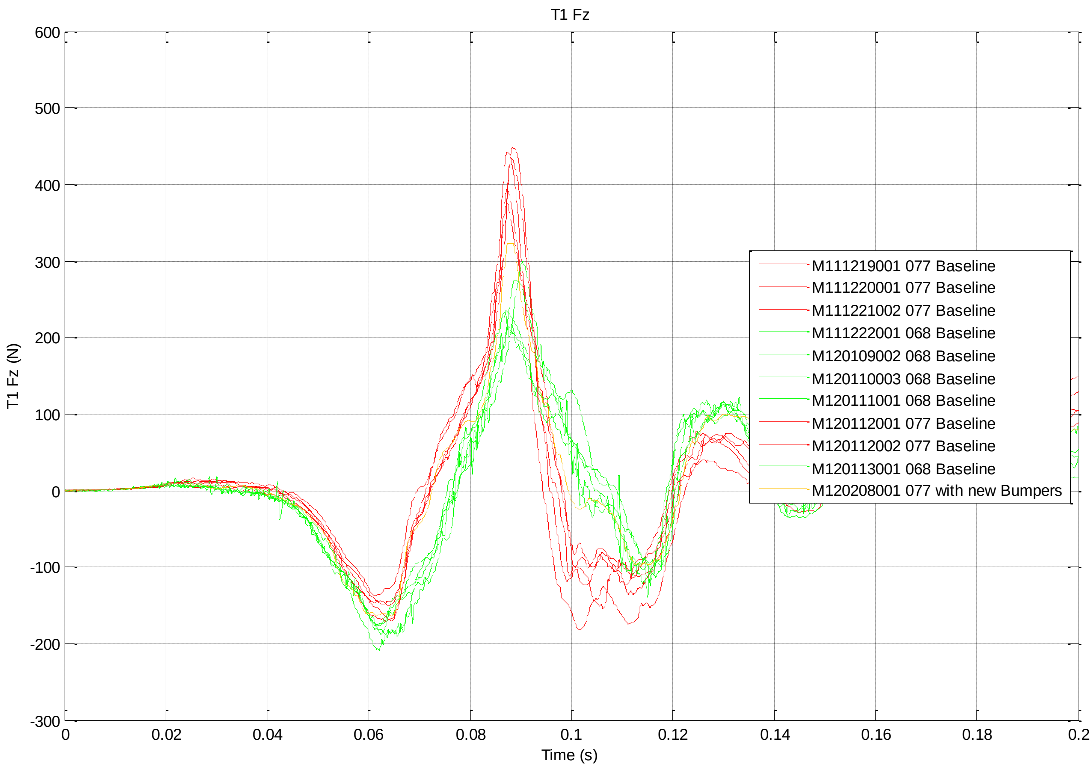


Figure 3-33: T1 Z-axis force for dummy 077 with standard thickness T2 and T3 rear bumpers

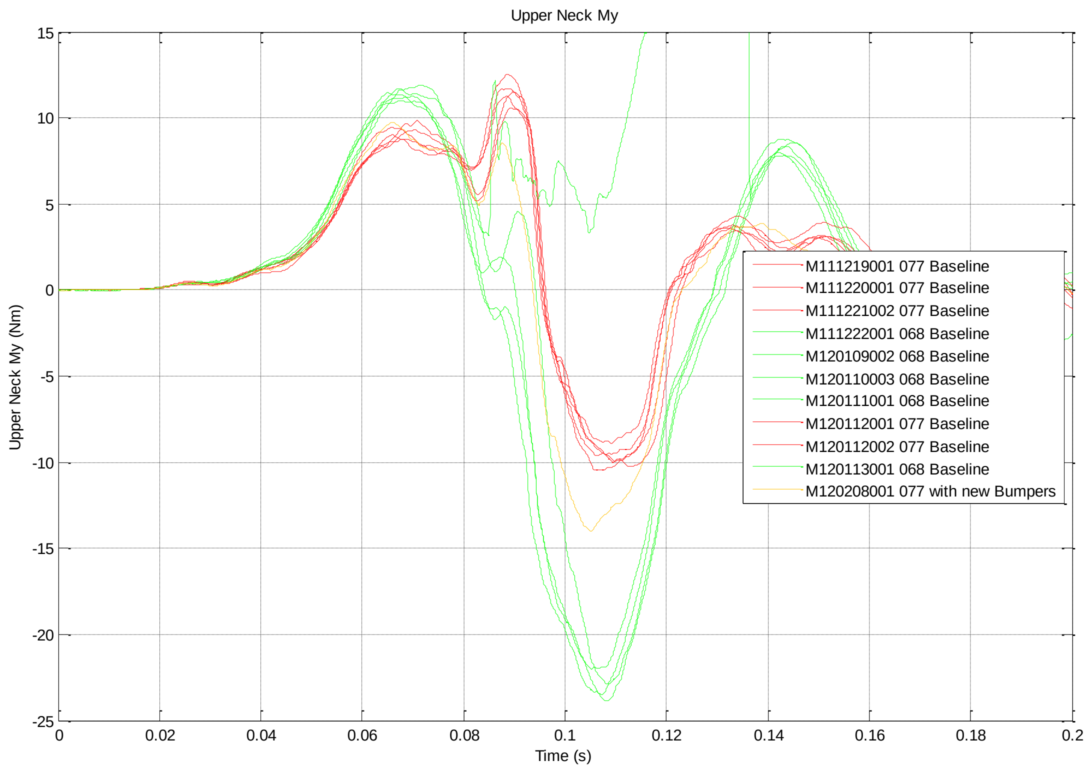


Figure 3-34: Upper neck Y-axis moment for dummy 077 with standard thickness T2 and T3 rear bumpers

3.8.1 Summary

The replacement of just two bumpers in the upper rear thoracic spine of dummy 077 had a pronounced effect on a number of channels, particularly those with poor reproducibility in the baseline sled tests. This change was also picked up in certification, and the dummy failed the Pot C certification requirement with the replacement bumpers. However, dummy 077 had a response close to the top edge of the Pot C corridor; a similar change in the stiffness of these two bumpers on dummy 068 (which was closer to the bottom edge of the Pot C corridor) would not have caused the dummy to fail, but would be expected to cause an equivalent change in seat test responses. This indicates the sensitivity of the seat test responses to bumper stiffness, and that tight control of bumper stiffness will be important for improving reproducibility.

3.9 Phase 8: Dummies 068 and 077 following Refurbishment of the Spines

The last Phase of testing involved re-testing dummies 068 and 077 once the spines of both dummies had been fully refurbished. The refurbishment was carried out a Humanetics, Heidelberg and involved:

- All cervical, thoracic and lumbar bumpers were replaced with bumpers from the same batch (six different specifications of bumper in total)
- All vertebrae were checked and replaced if the holes for the spine pins did not meet the tolerance defined by the Informal Group for the GTR BioRID

All spine pins were already to the current GTR-7 Informal Group specification, so none were replaced. Two tests were performed with each refurbished dummy, and full results may be found in Appendix M.

The first (positive) peak of pelvis acceleration was not affected by the refurbishment of the spine for dummy 077, and only slightly affected for 068 (see Figure 3-35). The second (negative) peak was unaffected for dummy 068 (see Figure 3-36). The magnitude of response for dummy 077 was at the low end of the range from the baseline tests, but the timing was quite different, with a substantial (5 ms) delay in the peak response).

T1 and upper neck Fz were markedly affected, with both the T1 Fz increasing for both dummies (Figure 3-37). The peak upper neck extension and flexion moments are shown in Figure 3-38 and Figure 3-39. The refurbishment of these two dummies has caused their upper neck My responses to converge considerably compared with the baseline tests. It seems that the time-shift in the second peak of the pelvis Az response has considerably reduced the second flexion peak response. Dummy 068 has moved closer to the force and moment responses of the refurbished dummies 006 and 007, but dummy 077 has moved away from their upper neck moment response. However, as will be shown in Section 3.10, there were marked differences in the bumper performance for these two pairs of dummies, plus any pre-existing variation in jacket and pelvis response were still present.

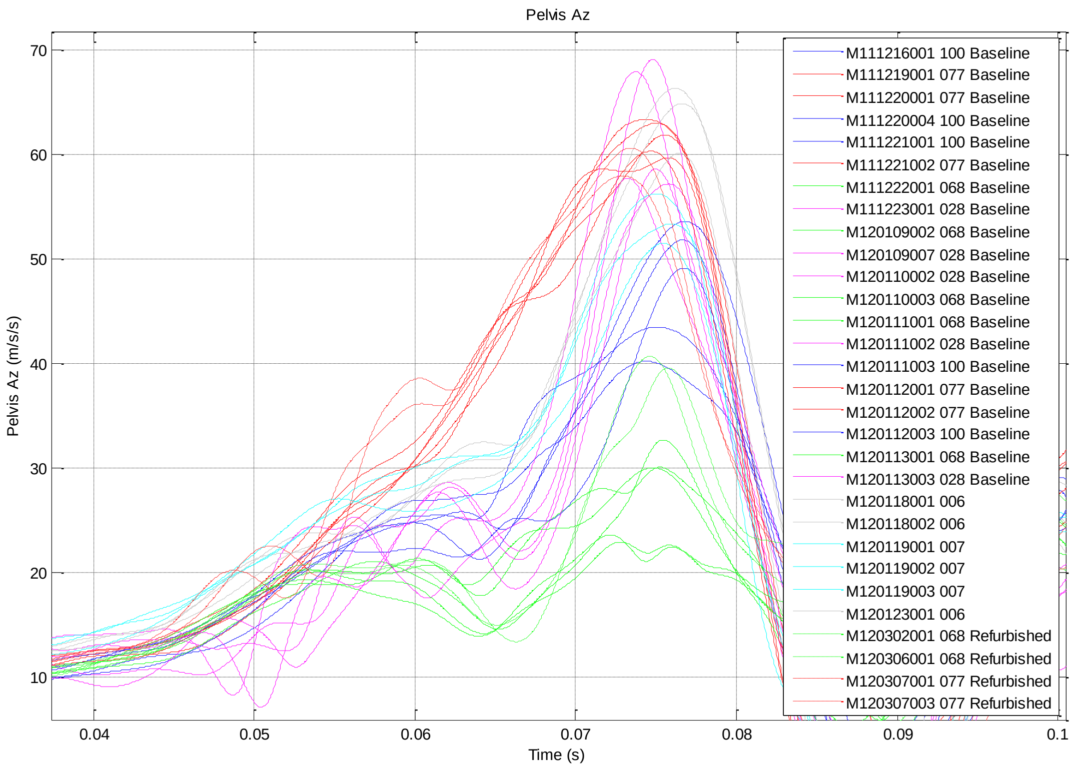


Figure 3-35: Pelvis Z-axis acceleration (detail) for dummies 068 and 077, following spine refurbishment

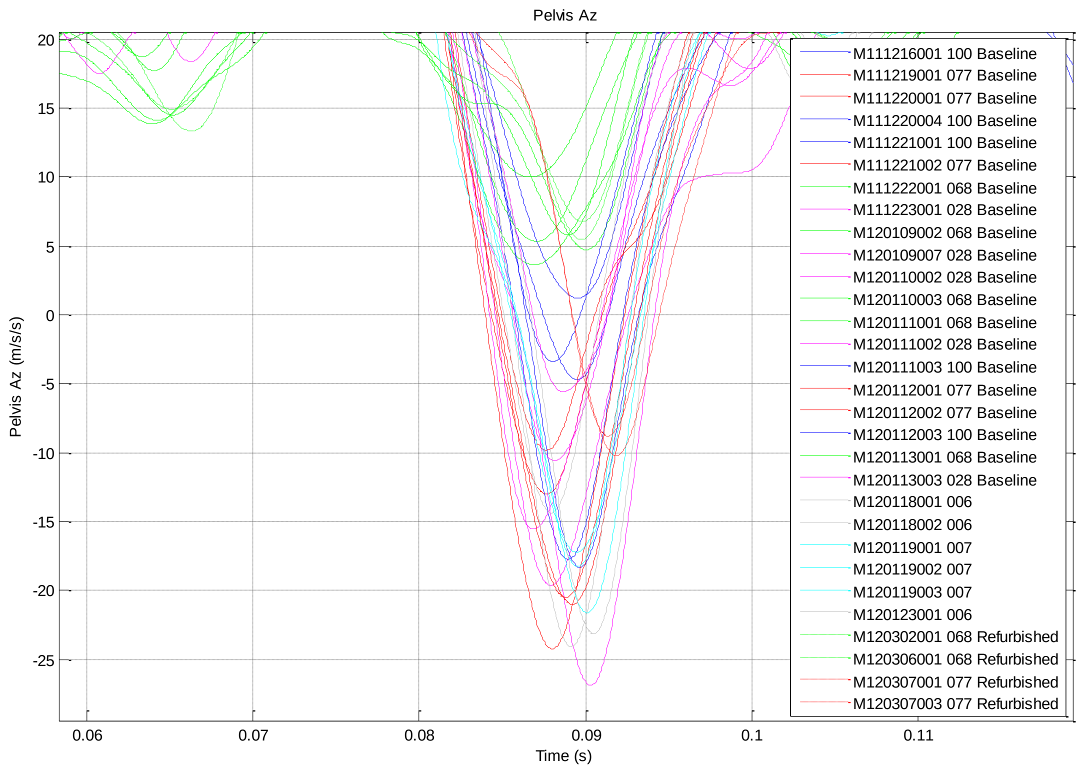


Figure 3-36: Pelvis Z-axis acceleration (detail) for dummies 068 and 077, following spine refurbishment

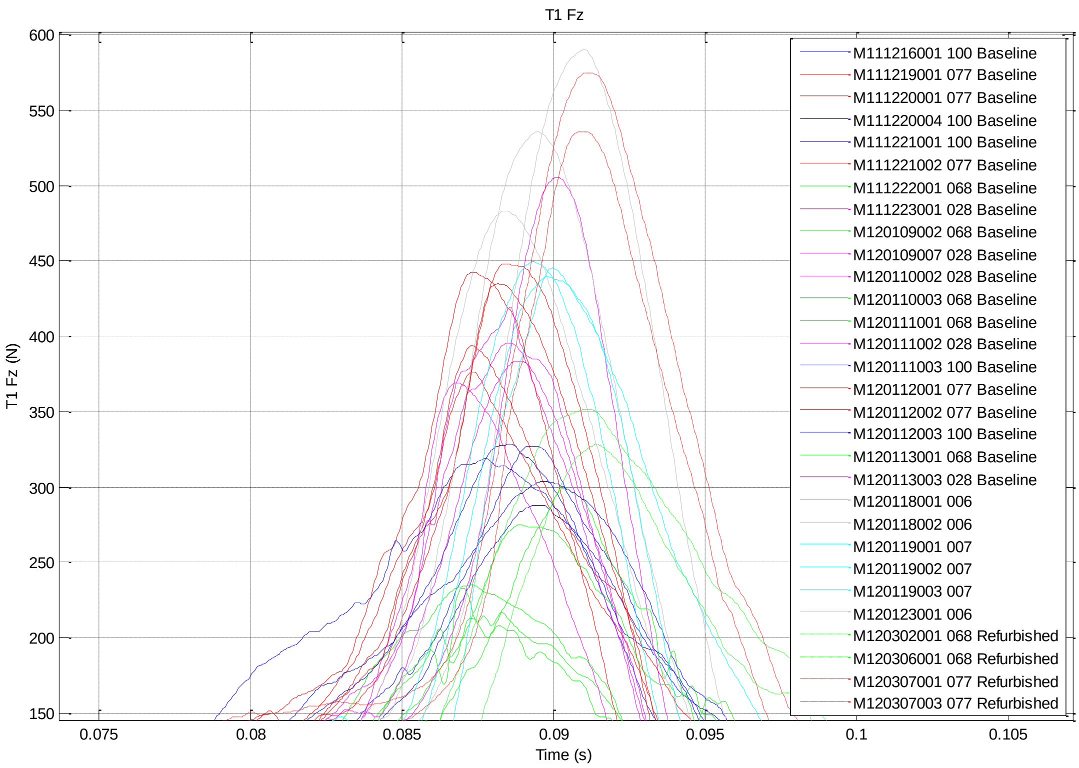


Figure 3-37: T1 Z-axis force (detail) for dummies 068 and 077, following spine refurbishment

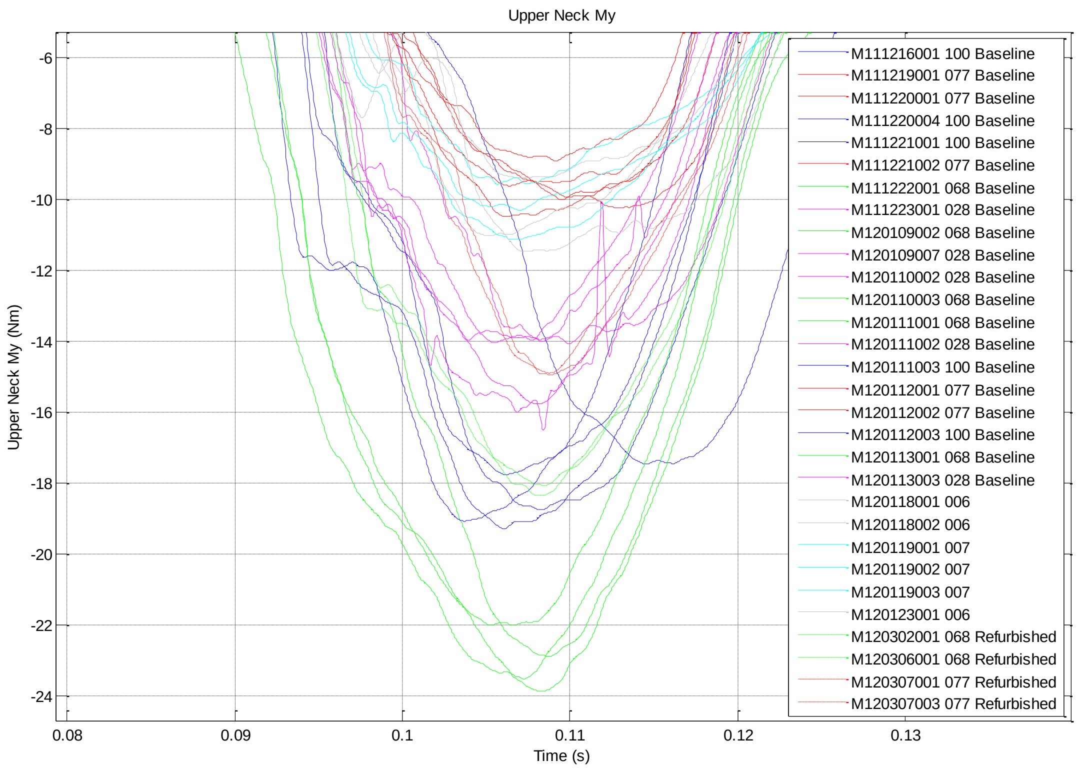


Figure 3-38: Upper neck Y-axis moment (extension moment detail) for dummies 068 and 077, following spine refurbishment

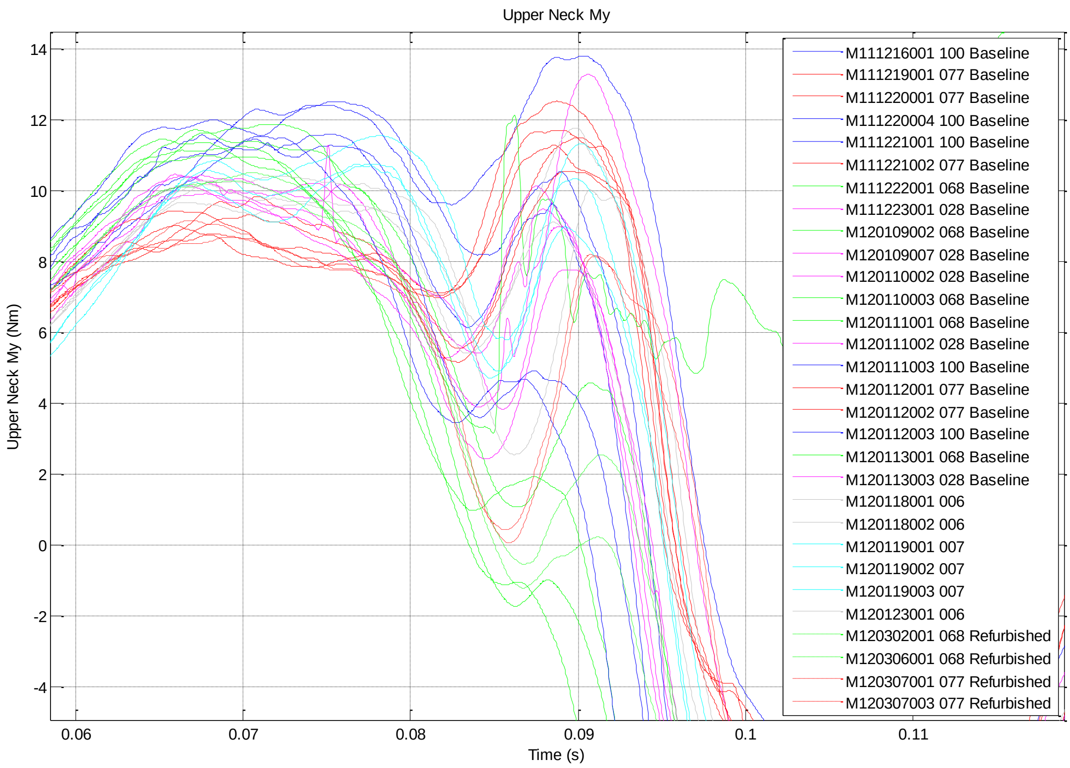


Figure 3-39: Upper neck Y-axis moment (flexion moment detail) for dummies 068 and 077, following spine refurbishment

3.10 Bumper Stiffness

The properties of the bumpers fitted to dummies 028, 068, 077 and 100 as used in the baseline tests is not known. However, when refurbishing dummies 006 and 007, and later dummies 068 and 077, Humanetics performed quasi-static compression tests on each batch of bumpers, for each of the six standard bumper types used in the BioRID II dummy. The results of these tests are shown in Appendix N, and are summarised in Table 3-2. The bumpers were manufactured as noted below:

- All dummy refurbished 068 and 077 bumpers from one manufacturing batch
- All dummy refurbished 006 and 007 bumpers from a different manufacturing batch
- Both manufacturing batches from the same batch of material

Table 3-2: Batch-to-batch variation of quasi-static compression test results for bumpers fitted to dummies 006/007 and 068/077

	Peak Compression	Mean Force
Black cervical front and rear (ARA-220)	0.19	-2.53
Yellow cervical rear (ARA-227)	0.98	-4.35
Black thoracic front (ARA-381-37)	9.78	8.12
Yellow thoracic rear (ARA-381-30)	0.85	14.26
Black lumbar front (ARA-521)	3.71	2.97
Black lumbar rear (ARA-520)	-0.66	28.77

The rear thoracic and lumbar bumpers both have substantial variation in the mean force, for very small variations in the input compression. This indicates a substantial difference in the stiffness of these two batches of bumpers. In contrast, the front and rear cervical, and front lumbar bumpers showed much lower stiffness variation between the two batches. The tests for the front bumper, which involved very small compressions, had relatively large variations on the input compression, but it would appear that the stiffness of these bumpers was also reasonably consistent between batches.

3.11 Certification Tests

3.11.1 Sled Test without Head Restraint

The without-head-restraint certification test results for all six dummies used in the test programme are shown in Appendix O.1. Appendix O.1.1 shows the certification requirements in table form; Appendix O.1.2 shows the test parameters (impactor force, sled acceleration and sled velocity); and Appendix O.1.3 shows the dummy responses. The key is explained as follows in Table 3-3:

Table 3-3: Explanation of the key for certification tests without head restraint

<table>
<tr><th>Key</th><th>Comment</th></tr>
<tr><td>No HR 006 3 Refurbished</td><td rowspan="2">Dummies 006 and 007 after spines refurbished</td></tr>
<tr><td>No HR 007 3 Refurbished</td></tr>
<tr><td>No HR 028 1 Pre-baseline</td><td rowspan="5">Dummies 028, 068, 077 and 100 prior to baseline tests (-1 and -2 denote repeat tests with the same dummy)</td></tr>
<tr><td>No HR 068 1 Pre-baseline-1</td></tr>
<tr><td>No HR 068 1 Pre-baseline-2</td></tr>
<tr><td>No HR 077 1 Pre-baseline</td></tr>
<tr><td>No HR 100 1 Pre-baseline</td></tr>
<tr><td>No HR 077 2 Post-baseline</td><td>Dummy 077 after the T2 and T3 rear bumpers were replaced</td></tr>
<tr><td>No HR 068 3 Refurbished</td><td rowspan="2">Dummies 068 and 077 after spines refurbished</td></tr>
<tr><td>No HR 077 3 Refurbished</td></tr>
</table>

It is notable that the corridors for the inputs (impactor force, sled acceleration and sled velocity) are very wide (±9.6%, ±10.7%, and ±5.3% respectively). In the context of a reproducibility target of CV ≤ 10%, the allowable range on the input to the certification test seems very large. The impactor force and sled acceleration responses for all of the tests shown in Appendix P.1 cover a much narrower range than these limits, so it would appear to be possible, as well as desirable, to reduce the range for these requirements. The response for the sled velocity cover a greater proportion of the (narrower) corridor, but it may also be necessary to reduce the width of this corridor to ensure an equivalent test for all dummies (see Section 4.1).

3.11.2 Sled Test with Head Restraint

The with-head-restraint certification test results for all dummies are shown in Appendix O.2. There are currently no requirement corridors for this certification test. It should be noted that pre-baseline upper neck My data for dummies 028, 068, 077 and 100 is not available. These tests were done with the wrong skull cap and the results cannot be used; however, Humanetics considered that the data for the other dummy channels would be reliable and it has been reported in the appendix. It is notable, though, that the upper neck Fz and Fx response is very different for these dummies and may also be unreliable.

It is notable that the sled velocity was higher for dummies 028 and 100, just as it was for the certification test without head restraint. It is possible that this indicates some fundamentally different property for these two dummies, because it is unlikely that the same two dummies received a more severe test condition with and without head restraint.

The total head rotation is *more* variable in the test with a head restraint than the test without a head restraint. Dummy 100 is particularly outlying in Pot B, C and D, and total head rotation response. Upper neck Fx for dummies 028, 068 and 100 is considerably outside the range for dummies 006, 007 and 077 (except for the dummy configuration with incorrect T2/T3 bumpers). These differences are far more apparent than in the upper neck Fx measurement in the test without a head restraint.

The upper neck My data for the refurbished dummies (006, 007, 068 and 077) are all very similar, and the bumper properties were similar for these dummies. The pre-refurbishment performance of the 068 and 077 dummies is not known, and the pre-refurbishment performance of the 006 and 007 dummies in the TRL seat test is not known, so it is difficult to draw solid conclusions from this data. However, it does appear that a narrow requirement of -2 to -5 Nm at 65-75 ms would have been met by all of the refurbished dummies, and failed by 006 and 007 pre-refurbishment, and by 077 with standard thickness T2/T3 rear bumpers.

3.11.3 Jacket Certification

Jacket certification tests were undertaken according to the specification in the draft BioRID certification test procedures document 'Certification Procedures for the BioRID II Crash Test Dummy', dated November, 2010 (see footnote page 17).

The jacket certification data for dummies 028, 068, 077 and 100 is shown in Appendix O.3. All pendulum impactor velocities were within specification (1.50 to 1.55 $m.s^{-1}$), and the impactor force response is reproduced in Figure 3-40 below. The sled velocity is at the very lower end or slightly below specification for two tests with dummy 068. All of the other tests, with all dummies, had a very similar peak velocity, although the timing varied according to the stiffness of the jacket. This may indicate that not all of the momentum of the impactor was transferred to the jacket for two of the tests with the jacket from dummy 068. These two tests are the lower pair of dummy 068 responses for impactor force and for sled acceleration. This implies that the jacket from dummy 068 was at the high end of the impactor force corridor, and above the sled acceleration corridor. It also implies that a much tighter corridor for sled velocity may be useful to ensure that a comparable test has been undertaken for every jacket. It is also notable that the softer jacket of dummy 100 markedly affects the duration of response in the test. As noted in the with- and without-head-restraint certification tests, this gives a phase change in the total thoracic rotation and upper neck forces and moments for this dummy. Any phase-change in the response of the dummy is likely to affect the response in seat tests.

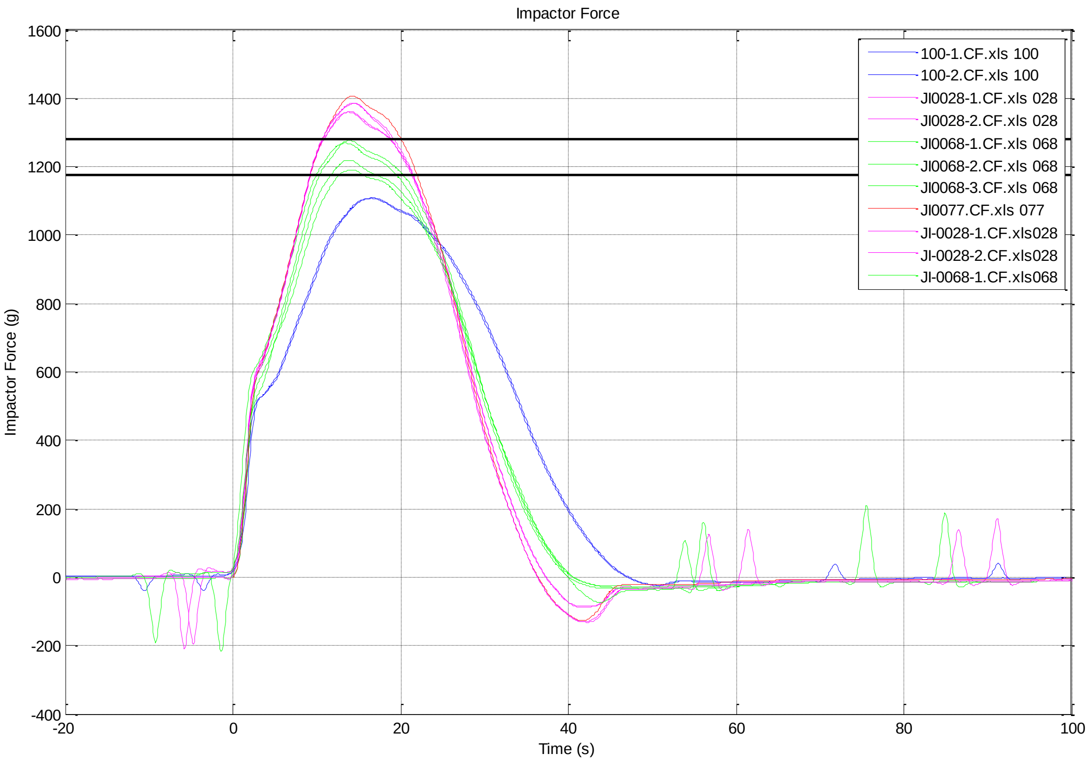


Figure 3-40: Jacket certification test – impactor force

In summary, the jacket responses were:

028	Too stiff (+5 to 7% *cf.* upper corridor)
068	At the upper limit or slightly too stiff
077	Too stiff (+9% *cf.* upper corridor)
100	Too soft (-5% *cf.* lower corridor)

3.11.4 Pelvis Certification

No pelvis certification test or requirements are currently defined, but pelvis certification-type tests were undertaken using a test procedure very similar to the jacket certification tests described in Section 3.11.3. This procedure had been trialled several years ago, but was not brought into routine use. The pelvis certification-type data for dummies 068 and 077 is shown in Appendix O.4. The results of impacts to the rear of the pelvis are shown in Appendix O.4.1, and the results of impacts to the base of the pelvis are shown in Appendix O.4.2. Only data from dummies 068 and 077 were available at the time of writing, but the pelvis certification tests for the other dummies is being performed and the data will be made available to the TEG.

In the tests to the rear of the pelvis, the peak impactor force was slightly higher for dummy 077 than for dummy 068. Much more noticeable was the slope of the force-time response, which may worth considering as a way of controlling pelvis stiffness. The peak sled velocity was very similar for both dummies, indicating that a comparable proportion of the energy of the impactor was transferred to the sled in all tests. However, the time to peak velocity was markedly different for the two pelvises. Again, control of this parameter may be useful.

The tests to the base of the pelvis showed a far greater difference between dummies 068 and 077. In fact, dummy 068 had a greater peak impactor force than dummy 077. It is thought that this was because the pelvis flesh on dummy 068 was so soft that the impactor penetrated right through the flesh and bottomed-out on the metal parts of the pelvis.

4 Discussion

4.1 Certification

The certification data was compared with seat test data in order to try and understand the correlation between the two. However, there are several key differences between the certification tests and a seat test that complicate this comparison:

- The pelvis of the dummy is replaced by a fixed (in translation – rotation is allowed) connection to the sled, so the pelvis, including pelvis flesh, plays no part in the response of the dummy in the certification tests.
  - It was shown in the seat test programme that the pelvis had a considerable effect on the key measurements that were found to have poor reproducibility (see Section 3.5). The pelvis stiffness of dummies 068 (soft) and 077 (hard) were also found to be markedly different in certification-type tests. Dummy 100 was felt to have a pelvis flesh as soft as dummy 068, and dummy 028 to have the hardest pelvis flesh of all four.
- The support of the back of the BioRID dummy in the certification sled tests is at one vertebral level.
  - This is quite different from the situation in a typical seat, where the dummy will be supported along most of the length of the back. This support may be distributed, if the seat back is relatively homogeneous, or may contain localised loading from localised structures in the seat back. In either case the support is likely to be different to the certification test.

Given that the pelvis response was found to be important, at least for the seat used in this test series, then it is recommended that certification of the pelvis is resumed, with tight corridors on the stiffness of the pelvis flesh. Control of pelvis geometry is also recommended.

For the baseline seat tests, dummy 077 was fitted with shorter bumpers in the T2 and T3 rear bumper positions. This was done to tune the Pot C response in certification tests. In one respect such tuning is effective: the tuning gives a T1 response that is more consistent with the other dummies, so a direct comparison of cervical spine response is possible.

However, if one of the outcomes of the certification test is to tune just the top few rear thoracic bumpers, then this may simply be compensating for a difference in stiffness lower down the spine. This may be the reason that replacement T2 and T3 rear bumpers in dummy 077 (see Section 3.8) gave an upper neck My and T1 and upper neck Fz response closer to the other baseline dummies, even though this modification meant that the dummy failed the certification test (the bumpers installed for the baseline tests, were thinner in order to pass the certification requirements).

This suggests that the certification test may result in a standardised T1 response in the specific loading scenario of the certification test, but may not standardise – or may even increase the range of – T1 response in seat tests. It seems the response of the spine at each level needs to be controlled in order to ensure reproducible measurements. It may be that it is possible to do this across groups of multiple vertebrae, or it may be necessary at the level of individual vertebrae. The largest group that is likely to be relevant is sections of the spine where a particular specification of bumper is installed, e.g. lumbar or thoracic spine. This was discussed during the test programme, and Humanetics developed a quasi-static spine stiffness test as a first attempt at controlling the localised spine stiffness for the whole spine. The test was performed in flexion and extension, with and without the thoracic/lumbar torsion pins engaged. Preliminary results were presented at the 9th GTR-7 meeting in mid-March, from tests with dummies with known differences in spine bumpers stiffness. However, the initial conclusion was that the test was not sensitive to differences in spine bumper stiffness.

It may be that batch-testing of the quasi-static stiffness of individual bumpers is required. The certification test(s) could then be used to confirm the performance of the head-neck-torso of the dummy (including the torsion pins, which are an important contributor to the stiffness of the spine), and to determine when age- and use-hardening have caused sufficient change in spine response that new bumpers are required. A limitation on this approach is that the lumbar and lower thoracic bumpers are not greatly loaded in the certification test, because the pelvis is fixed (in translation) and the spine is supported at a single point approximately half way up the thoracic spine. Therefore, changes in bumper performance at this level may not be detected. Also, flexion response at the lumbar and thoracic spine is not monitored in the certification tests, so the performance of the front lumbar and thoracic bumpers is not controlled. Furthermore, the properties of the front cervical bumpers are not as well controlled as the rear cervical bumpers, but they may be very important to the reproducibility of neck Fz forces and upper neck My moment, because the primary bending response of the BioRID cervical spine in this seat test series was flexion, not extension.

4.1.1 Certification Test without Head Restraint

Test Parameters

The impactor force, sled acceleration and sled velocity are all well within the requirements. Nevertheless, it is clear from the graphs in Appendix O.1.2 that the sled velocity in particular is rather variable. This seems to correlate with a greater Pot D extension response, although it is not known whether a greater sled velocity caused a greater Pot D rotation, or whether a difference in the stiffness of the dummy caused a change in the sled velocity. However, a much narrower requirement on the first peak of the sled velocity may help to ensure that the dummy responses are more easily correlated changes to the dummy such as jacket or bumper stiffness.

The requirements on impactor force and sled acceleration, which are inputs to the certification test, have a very wide tolerance (±9.6% and ±10.7% respectively). This seems excessively wide in the context of a target dummy reproducibility of a CV of 10%. It would appear to be possible, as well as desirable, to reduce the range for these requirements.

Pot A

The corridors for the Pot A response are very wide: even though the dummy responses are very varied, they only cover half the width of the corridor. It would appear that the slope of the response after the main flexion peak is more discriminating between dummies, because this seems better correlated to the seat test responses than the peak values.

Pot B

This requirement has reasonably wide corridors, but all dummies met the corridors quite easily, and there is no obvious correlation between these responses and the dummy responses in seat tests. It may be that the control on the neck response, together with the requirement to replace the neck bumpers at regular intervals (in terms of time, or number of tests, whichever is exceeded first), is sufficient to control this aspect of dummy response. However, given that the dummy responses are all close to the middle of the corridor, it would be reasonable to reduce the width of the corridor to ensure that the response is always reproducible.

It should also be noted that this requirement assesses the extension response of the neck, and it was noted in the seat tests that the flexion response was also very important to control.

Total Head Rotation (Pot A + Pot B)

This parameter has several corridors, which are very wide compared with the range of dummy performance in these tests. The corridors relate to peak extension response, but there is no obvious relationship between the peak extension responses and the upper neck My extension moments observed in the seat tests. However, there is an obvious correlation between seat test results and the slope of the Total Head Rotation response between 40 and 90 ms (prior to the corridor for the first peak at 100-110 ms. It is possible that a requirement on this slope may be beneficial.

Pot C

This corridor is already quite narrow (-16.5° between 73 and 78 ms; not less than -19.0° at any time). It is not known whether it would be practicable to reduce the width of this corridor, but it is notable that there are two distinct groups of responses within the test shown in Appendix O: Dummy 068 and 100 with greater rotation, and dummies 028, 077, 006 and 007 with smaller rotation. The order of the responses is a good match with the order of upper neck My in seat tests, which suggests that there would be merit in a reduced corridor width. This parameter is presumably affected by a combination of jacket stiffness and lumbar and thoracic spine stiffness, so meeting a narrower corridor may be possible with dummies with more tightly controlled jacket and bumper stiffness.

Pot D

No requirement in the current certification test procedure.

Very small difference between dummies for the first peak value, but the second (rebound) peak shows a wide variation between dummies. A narrow corridor (say -0.2° to -0.6°) at 85 ms may help to eliminate particularly soft or stiff lumbar response (although only in extension).

Total Thoracic Rotation (Pot C + Pot D)

Very wide corridor (-10° to -21°), which is not aligned with the peak response (the corridor is at 125-135 ms, the peak is at approximately 75 ms). A much narrower corridor – say -17° to -19° at 75 ms – would be required for this parameter to affect dummy performance.

Upper Neck Fx, Fz and My

The upper neck Fx, Fz and My responses in the certification test without head restraint show considerable oscillations, at approximately 3-4 times the frequency of the gross motion of the dummy.

Lower Neck Forces and Moments

The lower neck (T1) forces and moments are not included in the certification test. It is understood that this is primarily because of the difficulty of connecting the load cell to the data acquisition system at the certification laboratory. Test laboratories use a very wide range of connector types and pin-layouts for their crash test dummies, and it is not easy for one certification laboratory to accommodate all of these. For BioRID certification, the upper neck load cell is often swapped for a standard load cell by the certification laboratory. This makes certification easier and less expensive, but it means that the dummy has to be partially disassembled between certification and seat tests, which is not ideal. The T1 load cell is not swapped for certification because it would require far too much disassembly of the neck and performance of the dummy would almost certainly be affected.

4.1.2 Certification Test with Head Restraint

There are no dummy response requirements yet defined for the certification test with head restraint, and there were problems with the baseline with-head-restraint certification tests of dummies 028, 068, 077 and 100 prior to the test series which means that only limited information is available in this test condition.

As was noted for the test without head restraint, the sled velocity was higher for dummies 028 and 100. It seems unlikely that the same two dummies received a more severe test condition with and without head restraint, so this may be indicative of some fundamental difference between these two dummies and the other four dummies tested. This implies that tighter control of the sled velocity could be used to control dummy responses, but it is not clear what adjustments would be made to the dummy to alter the sled velocity.

Dummy 100 had a very outlying response for most of the rotation parameters in the certification test with head restraint, which was not apparent in the test without head restraint. The outlying response may have been related to the particularly soft jacket on this dummy. The test with head restraint also exposed greater differences in upper neck Fx for dummies 028, 068 and 100 compared with dummies 006, 007 and 077, although these data may not be reliable for four of the dummies.

Although the pre-baseline test data for dummies 028, 068, 077 and 100 is not available, post-refurbishment certification data shows very tight grouping for dummies 006, 007, 068 and 077, particularly at 65-75 ms, compared with pre-refurbishment dummies 006 and 007, and dummy 077 with short T2/T3 bumpers. Cervical bumper stiffness was also very similar for dummies 006, 007, 068 and 077, as shown in Section 3.10. This suggests that a requirement on upper neck My measurement in this test condition should be considered.

4.1.3 Jacket Certification

There was some indication in these tests that the sled velocity parameter is a possible way to ensure a comparable energy transfer into the jacket for each certification test. Ideally, this would be assessed for a larger population of dummies. This would make the jacket certification test itself more repeatable and reproducible, which would help to ensure a consistent assessment of jacket stiffness. The range of jacket stiffness in the baseline dummies was greater than the target reproducibility for the dummy. The jacket stiffness clearly affected the phase of responses in the sled certification tests, particularly for the jacket that was too soft. This has also been reported in other studies. Any phase-change in the response of the dummy is likely to affect the response in seat tests, so it is recommended that the jackets used in any future testing for the Informal Group comply with the jacket requirement. It is understood that Humanetics are currently compiling jacket test data in order to evaluate the current draft corridors, and that the current corridors may therefore change.

4.1.4 Pelvis Certification

The pelvis certification data for dummies 068 and 077 showed considerable differences between the stiffness of the pelvis flesh on the two dummies. The pelvis flesh for dummy 077 was markedly stiffer than that for dummy 068. This finding correlated well with the subjective evaluation of stiffness undertaken by the author, which also found that the pelvis flesh of dummy 100 was of similar softness to that of dummy 068, and that dummy 028 had the hardest pelvis flesh.

The pelvis was also found to be an important factor in the measured neck responses of the dummy, and pelvis stiffness seems to be well correlated to the observed variation in ramping-up behaviour with the four baseline dummies. It is therefore recommended that the pelvis certification test procedure is reintroduced with tight controls on pelvis stiffness. Examination of the few results available in this series suggests that consideration should be given to controlling the slope of the force-time response, not just the magnitude of peak force, in order to ensure similar pelvis stiffness across all BioRID dummies.

4.1.5 Bumper Installation

All front neck bumpers are automatically replaced every time that the dummy is certified, and it is recommended that this replacement occur at least every 4 months. Rear cervical bumpers are replaced as required, based on inspection of their condition.

The User Manual (dated 22 November, 2010) notes that the T1 bumpers are positively located when they are reinstalled, because the recess in which they are installed is approximately the same shape as the bumper. This should ensure that the bumpers are the correct distance from the pivot point of the joint. However, the T1 load cell drawing in the drawing package on the UN web-site shows the recess to be 14.7 or 15 mm long (from front to back), while the bumper is either 10 or 9.8 mm long. This would clearly allow considerable variation in the position of the bumper.

The other cervical bumpers are not positively located, but the rectangular bumpers (with rounded corners) are fitted into a circular recess that allows ±1.0 mm fore-aft movement for the yellow bumpers (see illustration in Figure 4-1) and ±1.25 mm fore-aft movement for the black bumpers located in the front and top three rear positions. Ignoring the tolerance on the part, and assuming that the T1 bumpers are correctly located, this gives a range of head-to-neck angles at which the bumpers at each joint are just in contact with the next vertebra. For neck extension this range is nearly 12° and for flexion it is nearly 13°. If the T1 bumpers are placed at the extreme ends of the range of their recesses, the neutral range would increase by more than 4°.

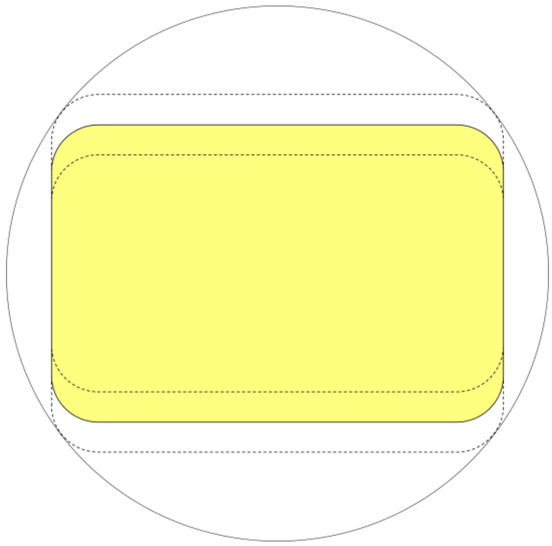


Figure 4-1: Schematic of yellow bumper and recess (plan view)

In practice it is unlikely that different dummies would show neutral neck positions across the whole of this range, but it is also clear that more precise location of the bumper would improve the consistency of engagement with the bumpers, and should therefore improve the force-angle response of the neck.

The thoracic bumpers are aligned with the edge of the vertebral body (rear bumpers) or 2 mm from the edge (front bumpers). The rear bumpers should be very easy to align consistently in the fore-aft direction, with more scope for errors in the position of the front bumpers.

Humanetics use a tool to ensure that the positioning of all bumpers is consistent. However, the tool is not part of the BioRID drawing package on the GRSP web site. Some BioRID owners perform their own certification and maintenance, and at the BioRID drawing package meeting it was agreed that any tools that may be required by users of the dummy should be included in the drawing package. Therefore it is recommended that the bumper positioning tool is included in the drawing package, and a description of its correct application be provided in the User’s Manual for the dummy.

4.2 Seat Tests

4.2.1 Test Repeatability

The repeatability of the seat tests was excellent, with a very repeatable pulse and no identified degradation in seat response over a large number of tests. The modifications to the seat to ensure robustness were therefore successful, possibly more successful than expected – several spare seats were produced, but they were not required. The head restraint, however, did yield very slightly in each test (and had to be replaced twice) and it would be better if this was strengthened for any future testing.

Most importantly, the sled and seat responses were sufficiently repeatable for the tests to be used to evaluate the reproducibility of the dummy, and the effect of changes to the dummy build level.

4.2.2 Dummy Response

4.2.2.1 Baseline Tests

Each dummy had small variations in its initial seating position, but the outlying dummies in terms of the channels with the most variable responses (upper and lower neck Fz; upper neck My), had quite similar seating positions. Therefore, while this may be influential – particularly if seat back structures are closely aligned to the edge of e.g. pelvis structures – it does not seem to be of primary importance in the present test series.

There are some differences in the accelerations measured in the dummies, especially at the pelvis where both the Z- and X-axis accelerations are repeatable for each dummy, but different between dummies. The T1 X-axis acceleration response was reproducible for the first peak, but not for the second. It is thought that the first peak was dominated by the response of the seat cushion and the second by the jacket, because there was evidence that the upper spine of the dummy just bottomed-out against part of the seat reinforcement structure. The T1 responses were a good match for the jacket stiffness data, except for dummy 100: this dummy had the softest jacket, but a similar T1 response to dummy 068, which had a medium stiffness jacket. There are several possible reasons for this:

- Spine stiffness is also likely to affect T1 acceleration. The spine stiffness for the dummies used in the baseline tests was unknown, so any potential correlation with this parameter cannot be assessed.
- The jacket certification test loads the front of the jacket, whereas the much thinner rear of the jacket is loaded in seat tests. The jacket test may quantify the bulk stiffness of the jacket material, but any variation in the thickness of the material covering the spine would not be accounted for.
- The jacket opening is along the centre-line of the spine, and when the jacket is installed on the dummy, this gap may not be consistent. This could lead to a different effective stiffness of the flesh over the spine, and therefore potentially a different interaction with the seat back

The T1 and upper neck Fx shear forces were repeatable and reproducible, with the exception of one test that had a loose head restraint. T1 My was also repeatable and reproducible.

However, T1 and upper neck Z-axis forces were repeatable, but not very reproducible. Peak T1 Fz, occurring at 90 ms, varied between 200 N for dummy 068 and over 400 N for dummy 077. Peak upper neck Fz, also at 90 ms, varied from 600 N for dummy 068 and 1100 N for dummy 077. The upper neck My moment response was very repeatable, but showed poor reproducibility between dummies. X- and Y-axis accelerations peak at about 90 ms, and have returned to zero by approximately 110 ms, so there is little external loading on the dummy at the time of peak upper neck extension moment (negative My).

Marker tracking using a calibrated camera system was used to evaluate the kinematics of the dummies in the baseline tests. It was found that the head, T1 and pelvis angles (in a sled-based co-ordinate system) were repeatable, but not reproducible. The head-T1 angle was also repeatable, but not reproducible. This seemed to be related to significant differences in the ramping-up behaviour of the four dummies, which also seemed to correlate well to the internal dummy measurements that showed insufficient reproducibility. In contrast, the OC to T1 displacement, in a seat back co-ordinate system, was found to have much better reproducibility, with a Coefficient of Variation of 11.8%. This is slightly greater than the target CV of 10% usually used for certification- and biofidelity-type tests, but is good given the extra complexity of a padded seat test and especially given the large differences in the ramping-up behaviour of the dummies. It may be that improvements to the dummy to control the ramping-up behaviour better would also improve the reproducibility of the OC-T1 displacement measurement, as well as the measured head, T1 and pelvis angles.

It was also noted that T1 Fz and T1 My were markedly higher when the dummy was restrained by the seat-belt after rebounding than during the timescale when the loads in the dummy are normally assessed. The rebound in these tests may have been more vigorous than a standard seat test. However, the seat back was critically damped in rebound - i.e. the damping returned the seat back to its initial position with no overshoot – which was intended to avoid excessive rebound loading on the dummy. Therefore, if limits are set on these parameters in order to control the risk of whiplash, those limits may be greatly exceeded in rebound.

After the baseline tests were completed, it was noticed that the head restraint had yielded slightly in each test (<1 mm). This meant that the posture required for the BioRID dummy to achieve the target backset was fractionally different in each test. Nevertheless, the response of each dummy – whether tested at the beginning or end of the series – was repeatable. This suggests that the dummy was not sensitive to these small differences, and that the seating procedure was adequate to achieve repeatable results with the seat used. It should be noted, however, that there was no assessment of the reproducibility of the BioRID target backset measurement, because the same backset target was used in every test.

4.2.2.2 PDB Dummies

Previous reports (Bortenschlager *et al.*, 2009) have shown a range of performance from eight BioRID II dummies tested by PDB. It should be noted that these dummies were not fully to the current build and certification level specified by the Informal Group. However, more recent testing with two of the outlying dummies (serial numbers 006 and 007) showed continuing differences between the dummies, even though they had been updated and recertified.

Both dummies were subsequently tested by OSRP in the US and re-tested by PDB in 2011 and the results were presented at the 8th GTR-7 Informal Group meeting in December 2011 (presentations not available from the UNECE web site at the time of writing). Both studies found differences between the two dummies.

Dummies 006 and 007 were subsequently refurbished and recertified by Humanetics. The refurbishment included the following:

- All cervical, thoracic and lumbar bumpers were replaced with bumpers from a single, new production batch
- The tolerance on pin holes in each vertebra was checked, and non-compliant (too tight or too lose) vertebra were replaced
- All spine pins were replaced with the latest specification stainless steel pins

Following this refurbishment, both dummies were tested on the TRL seat and their performance was found to be very similar. Indeed, both dummies behaved very much like dummy 077 from the baseline test series, particularly with respect to the upper neck My moment. The original PDB tests with these dummies, plus all subsequent testing by PDB and OSRP, used the Euro NCAP 'low severity' pulse and a hard 'rally' car seat that would be expected to give different results to the more severe draft GTR-7 pulse and the production-based seat used in the present test programme. However, given the differences in Z-axis neck forces and upper neck My observed in the baseline test series with dummies 028, 068, 077 and 100, it would appear that the full refurbishment and tight control of bumper characteristics between the dummies eliminated most of the variation between dummies 006 and 007, at least in this test configuration.

The refurbished dummies 006 and 007 also show very similar upper neck My and head rotations in the certification test with head restraint, where archive data from the two dummies showed notable differences between the dummies, particularly for upper neck My.

The certification test without head restraint shows differences between the dummies, even though their performance in the seat test is very similar. It is possible that the certification test without head restraint does not expose the differences between the dummies observed in seat tests because the rebound phase is not monitored in the certification test. By contrast, the certification test with head restraint and a typical seat test both show differences between the dummies as the head of the dummy is stopped and the dummy starts to rebound.

This does not mean, however, that the certification test without head restraint is not useful. The current certification test is controlling numerous aspects of dummy performance, but it would seem from the result of this test programme that other aspects need to be better controlled.

Jacket and pelvis certification test performance for these two dummies is currently under investigation. Especially of interest is the comparison with the four baseline dummies from this test series, for which dummy 077 had very similar response to the refurbished 006 and 007 dummies.

4.2.2.3 *Dummy Reproducibility Investigations*

Swapping the spines between dummies 068 and 077 considerably reduced the variation in their responses compared with the baseline tests. However, swapping pelvises between the same dummies had a somewhat larger effect on their responses, for the neck forces and moments that had been observed to have poor reproducibility in baseline tests. This indicates that the pelvis was also a key factor in this test series, and it is known from the pelvis certification tests that the pelvis flesh of these two dummies had a very different stiffness. Much better control of the pelvis flesh stiffness is therefore strongly recommended. It should be noted that the effect of the pelvis may have been greater in this test series, and in the PDB Recaro seat test series, because the lower seat back is relatively rigid in both of these seats compared with some production seats, particularly those with a single-sided recliner mechanism. Therefore, pelvis stiffness variations may not affect the dummy response in some seats, but clearly will affect the response in seats with stiffer structures in the lower seat back.

The stiffness of the spines of the baseline dummies was not known in detail, other than what can be inferred from the certification tests. These tests primarily load the cervical and upper thoracic spine in extension, with little loading to the front of the cervical spine or to the front or rear of the lower thoracic and lumbar spine. An attempt was made to develop a quasi-static test of the stiffness of different regions of the spine, but this was not sensitive to known variations in the stiffness of bumpers in refurbished dummy spines, so this seems not to be a suitable test. However, it is clear that improved control of bumper performance is required. It may be that tight tolerances on a quasi-static compression test for bumpers *before* they are installed in the dummy is required.

Overall, it was clear that improvements to both spine and pelvis response were required to make substantial improvements to the reproducibility of the BioRID dummy in this test condition. Either one of these on their own would not improve reproducibility by more than 50%. Pelvis response and spine straightening would also both affect the ramping-up response of the dummy. This was found to have poor reproducibility, and it would be reasonable to assume that this would have a substantial effect on other dummy parameters. It would also be beneficial to improve the consistency of jacket stiffness.

4.2.2.4 *Updated Baseline Dummies*

The two outlying dummies from the baseline test series were refurbished and recertified by Humanetics. Additional tests of spine stiffness in flexion and extension were also performed. The dummies were then re-tested on the TRL seat. T1 and upper neck Fz were markedly affected, with the T1 Fz increasing for both dummies. The peak upper neck My flexion (before and after head restraint contact) and extension moments converged substantially following refurbishment. This demonstrates the benefit of having identical bumpers in both dummies, and therefore the requirement for better control of the bumpers than is achieved with the current certification process.

The upper neck My response of the refurbished dummies 068 and 077 was not identical to the refurbished dummies 006 and 007. In fact, the response of dummy 077 became less comparable with dummies 006 and 007. However, it was also found that the stiffness of the rear thoracic and lumbar bumpers was substantially different for these two pairs of dummies, despite the two batches of bumpers being produced from the same batch of raw material. Furthermore, there were pre-existing jacket and pelvis flesh stiffness variations between dummies, which would also affect the measurements. The upper neck My in the certification test with head restraint was almost identical for dummies 006, 007, 068 and 077, which indicates that this measurement in the certification test was not sensitive to the difference in lumbar and thoracic bumper stiffness and jacket stiffness. The test also does not incorporate the pelvis, so it cannot account for pelvis stiffness. It is recommended, therefore, that any future testing for the GTR Informal Group uses dummies that meet the jacket certification corridor, that meet a re-introduced pelvis stiffness requirement, and have well-controlled bumper stiffness. If this is shown to improve the reproducibility to an acceptable level for those channels that are adopted for use in the GTR, then it would also be prudent to assess the age-hardening effect to ensure that the current recommendation to replace front neck bumpers every four months is adequate, and to check whether a similar requirement should be introduced for the other spine bumpers.

4.2.3 Neck Flexion

Note that the neck shows very little extension, even with the relatively large backset used in this test series. The head translates rearwards, and rotates slightly rearward (in extension); however, the T1 rotates rearwards to a greater extent, so there is a net flexion response at the neck that peaks at the same time as the peak head X-axis acceleration (90 ms). In this test series, dummy 068 then moves to extension, with a peak at the time of peak upper neck extension moment (110 ms). Dummy 077 never goes into extension, but has a minimum at 110 ms that is still an overall flexion on the neck. Dummies 028 and 100 have a small extension, between the other two dummies, at this time. The difference in head-T1 rotation angle between dummies 068 and 077 is approximately 10° throughout the time from maximum to minimum angle.

It is perhaps surprising that the primary neck response in these tests is flexion. This means that the majority of the loading to the neck bumpers is to the *front* bumpers, which are not greatly exercised in the standard certification test without head restraint. The front bumpers affect the first peak requirement in both the Pot A and Pot B responses in the without-head-restraint certification test, but the loads on the neck at this time are low because they are due only to the inertia of the head. This may mean that differences in front cervical bumpers are not as apparent as they are in a seat test.

This finding seems to correlate well with information on the development of injury criteria for use with the BioRID dummy presented by Japan and the US at the 9th GTR-7 Informal Group meeting in mid-March. Both studies indicated a relationship between *flexion* response and injury.

The front cervical bumpers are also permanently compressed when installed in the neck, including when the neck bracket is fitted to support the neck in a neutral position between tests; hence the recommendation that the front bumpers are replaced at every certification, or every four months, whichever occurs earliest.

4.3 Dummy Design

At the 9th GTR-7 Phase 2 Informal Group meeting in March 2012, TRL recommended that the rear profile of the BioRID pelvis, and particularly the pelvis bone, is made smooth in order to avoid discontinuities in the interface with structures in the lower rear part of the seat. The pelvis bone and flesh are based on parts from the Hybrid III frontal impact dummy, the uneven profile of the rear of the pelvis would not be expected to affect test results in a frontal impact. However, it may affect results for rear impact testing, depending on the stiffness of structures in the lower seat back.

As part of the discussion on this it was also suggested that the instrumentation access cavity at the rear of the pelvis should be covered with a metal plate, and the remaining cavity filled with a foam insert. A metal cover is actually defined in the BioRID drawing package (on assembly drawing ARA-500, which references Hybrid III part 78051-13). A foam insert would be beneficial to give a smoother profile to the rear of the pelvis flesh, but some smoothing of the pelvis bone may also be beneficial.

4.4 Future Testing

This test programme has identified a number of dummy characteristics that should be more tightly controlled in order to improve reproducibility of the BioRID II dummy for use in regulation. However, it is not known how tightly these parameters need to be controlled. Further testing would be required to validate any improvements to the dummy and determine whether they are sufficient to deliver satisfactory reproducibility.

It is recommended, therefore, that the dummies used in any future testing for the GTR Informal Group:

- Meet the jacket certification corridor
- Meet a re-introduced pelvis stiffness requirement
- Have well-controlled bumper stiffness, at least equivalent to that of the hardness tolerance specified in the drawing package

It is also recommended that consideration be given to making the pelvis bone profile smoother, and filling the gap in the rear of the pelvis flesh that is used to access the pelvis accelerometers.

If this is shown to improve the reproducibility to an acceptable level for those channels that are adopted for use in the GTR, then it would also be prudent to assess the age-hardening effect to ensure that the current recommendation to replace front neck bumpers every four months is adequate, and to check whether a similar requirement should be introduced for the other spine bumpers.

5 Conclusions

A large programme of sled tests has been conducted to evaluate the repeatability and reproducibility of the BioRID II dummy. The test condition was highly repeatable, with a very repeatable pulse, a well-controlled seat back response, and minimal observed degradation of seat foams across the test programme. Very slight yielding of the head restraint was observed in each test, but this did not affect the repeatability of tests with a single dummy, so was not considered to be a significant factor in most tests. The head restraint was replaced twice during the test programme, when the amount of yielding increased markedly. The sled and seat responses were considered sufficiently repeatable to be used to evaluate the reproducibility of the dummy, and the effect of changes to the dummy build level.

Some reproducibility issues were identified, particularly for T1 and upper neck Fz, and for upper neck My. It should be noted that the GTR-7 Informal Group has not yet selected injury or seat assessment criteria for use with the BioRID II dummy, so it is not known whether any of these channels would be used in the regulation. However, there was also poor reproducibility for the ramping-up behaviour of the dummy, which would be expected to be fundamental to the reproducibility of dummy measurements in general.

There was little external loading on the dummy, assessed by the accelerometer measurements, at the time of peak upper neck My extension moment, which was the least reproducible measurement in this test series.

Dummy kinematics were generally repeatable, but not reproducible. This included head, T1 and pelvis angle, as well as head-T1 angle. These measurements, as well as the internal dummy measurements with identified reproducibility concerns, may well be related to large differences in the ramping-up behaviour observed between dummies. The ramping-up varied by over 20 mm across the four baseline dummies tested in this programme.

As a result of these findings, the planned test matrix was revised to focus on an extensive programme of tests to attempt to identify which dummy characteristics were responsible for the observed reproducibility issues, and to identify whether updates may be required to the certification procedures in order to ensure dummy reproducibility. Both the pelvis and spine characteristics were found to significantly influence the dummy measurements for which poor reproducibility was observed.

It was also observed that the primary neck response in these tests was *flexion*, not extension. This correlates well with recent findings reported to the GTR-7 Informal Group by Japan and the USA, which found a correlation between neck flexion and injury in accident replication simulations and PMHS studies respectively.

The present certification tests may not adequately control front cervical spine bumpers characteristics, which will be important for flexion response. The certification sled test also does not include the pelvis, so cannot be used to control pelvis response, and does not substantially load the lumbar bumpers, so does not control these parts of the dummy. Furthermore, it is possible that the way that the upper rear thoracic bumpers may be adjusted to tune the dummy to the present certification requirements may actually increase the variability between dummies in some seats. This is because the spine of the BioRID dummy is supported at the mid-thoracic level, but adjustments are only made to the top few bumpers: if the thoracic spine is too stiff, shorter bumpers are installed in order to get the T1 angle to meet the requirements. However, this means that the lower part of the thoracic spine is still too stiff, while the upper part of the thoracic spine may be too weak. This may lead to differences in dummy performance in seat tests, when the support of the spine is markedly different to that in the certification test.

Overall, in this test series it was found that the BioRID dummy was repeatable, but kinematics and several neck force and moment channels had poor reproducibility. A number of dummy characteristics were identified that seem to correlate well with the observed differences in behaviour, and recommendations have been made for how to improve the performance of the dummy.

6 Recommendations

The following recommendations are made based on the results of the testing carried out in this programme:

- Ensure that reliable certification data is available for all dummies prior to any new test programme.
- Ensure that all dummies meet the jacket certification requirement, whether this is the current requirement or a new requirement based on a larger database of jackets currently in use.
- Ensure that the pelvis response of all dummies meets tight requirements on the stiffness of the pelvis flesh.
- Tuning Pot C response by changing just the top rear thoracic vertebrae should not be undertaken. There is a risk that this will give a discontinuity in thorax extension stiffness that will not be apparent in the certification tests, but which may be important in seat tests. Bumpers should be replaced as a complete set (i.e. all thoracic rear bumpers at one time).
- The bumper installation tool should be included in the drawing package, because some BioRID owners perform their own certification and maintenance and this tool is necessary to ensure consistent positioning of the bumpers (and therefore a reproducible neutral neck angle between dummies). A description of the correct application of the tool should be included in the User's Manual.
- The primary neck bending response in this seat test series was flexion, not extension, which will be controlled by the front cervical bumpers. However, these bumpers are not as well controlled in the certification tests as the rear bumpers. A better way to check the performance of these bumpers is recommended.
- The tolerance on input parameters for the certification sled tests should be tightened, because currently the input for the certification test can be as variable as the target dummy reproducibility.
- Certification test without head restraint
    - The corridor width for the Pot A response should be reduced. Consideration should be given to controlling the slope of the response after the main flexion peak, because this seemed to be better correlated to seat test responses than the peak values.
    - The corridor width for the Pot B response should be reduced.
    - The corridor width for the Total head rotation (Pot A + Pot B) response should be reduced. Consideration should be given to controlling the slope of the response between 40 and 90 ms, because this seemed to be better correlated to seat test responses than the peak values.
    - Consideration should be given to reducing the width of the Pot C corridor, because these responses seemed well correlated with upper neck My response in seat tests. This may require tight control of lumbar and thoracic bumper stiffness, and jacket stiffness.

    - There is no requirement on the Pot D measurement in the current certification procedure. However, a narrow corridor (e.g. -0.2° to -0.6°) at 85 ms may help to eliminate particularly soft or stiff lumbar extension responses.
    - Consideration should be given to defining a much narrower corridor for total thoracic rotation (Pot C + Pot D). A corridor of e.g. -17° to -19° at 75 ms would be required to affect dummy performance, within the range of performance seen in this seat test series.
    - The reason for the oscillations in upper neck Fx, Fz and My responses in the certification test should be investigated.
    - Ideally, if lower neck loads are used in seat assessment, they should be included in the certification tests. It is understood that this is currently difficult due to the large variation in connectors used at different laboratories. However, this would become much easier if in-dummy data acquisition systems become more common.
- Certification test with head restraint
    - Additional comparative certification test and seat test data are required before with-head-restraint certification requirements can be defined; however, the test appears to discriminate for some aspects of dummy performance more clearly than the test without head restraint. Therefore, the test with head restraint should continue to be used during the further work of the BioRID TEG.
    - Consideration should be given to setting a narrow requirement of -2 to -5 Nm at 65-75 ms for upper neck My.
- Jacket certification
    - All dummies should have jackets that meet the jacket certification requirement. The current draft requirement may be updated following a review underway by Humanetics at the time of writing.
    - Consideration should be given to controlling the slope of the impactor force-time response, not just the magnitude of peak impactor force.
- Pelvis certification
    - It is recommended that the pelvis certification tests to the base and rear of the pelvis are re-introduced.
    - Consideration should be given to controlling the slope of the impactor force-time response, not just the magnitude of peak impactor force.
- Excessive play was noted in the H-point tool for several of the dummies tested in this programme. While the play was clearly not a primary factor in dummy reproducibility issues, it is recommended that the play in the H-point tool is reduced in order to ensure more consistent positioning of the dummy.
- A smoother rear profile for the pelvis bone geometry is recommended, including filling the access gap to the pelvis accelerometers. Relocation of the accelerometers should also be considered.

- Further testing should be performed to validate any improvements to the dummy and determine whether they are sufficient to deliver satisfactory reproducibility
- It is recommended that the dummies used in any future testing for the GTR Informal Group:
    - Meet the jacket certification corridor
    - Meet a re-introduced pelvis stiffness requirement
    - Have well-controlled bumper stiffness, at least equivalent to that of the hardness tolerance specified in the drawing package
- If this is shown to improve the reproducibility to an acceptable level for those channels that are adopted for use in the GTR, then it is also recommended to assess the age-hardening effect to ensure that the current recommendation to replace front neck bumpers every four months is adequate, and to check whether a similar requirement should be introduced for the other spine bumpers

7 Dissemination

The results from the test programme were presented and discussed in detail at a series of BioRID TEG meetings, including:

- 14 December 2011: Webex
- 31 January 2012: Webex
    - TRL-EC Presentation 2012-01-31.pdf
- 23 February 2012: Face-to-face meeting at BASt
    - TRL-EC Presentation 2012-02-23.pdf
- 14 March 2012: Webex
    - EC-TRL Presentation 2012-03-14.pdf

An overview of the test programme, the design of the seat, results, and recommendations arising from the project was presented to the UN GTR-7 Informal Group at the 19-20 March, 2012 meeting in London.

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