IMPROVED UNDERSTANDING OF PASSENGER BEHAVIOUR DURING PRE-IMPACT EVENTS TO AID SMART RESTRAINT DEVELOPMENT

Richard Morris
Gabrielle Cross
MIRA Ltd.
United Kingdom
Paper Number 05-0320

ABSTRACT

The PRISM project is a European Commission funded 5th Framework project that is intended to determine appropriate smart restraint technologies for Europe.

This paper describes a volunteer study undertaken as part of the PRISM project. The purpose of the study was to gain an understanding of how passengers "brace" and react during pre-impact vehicle manoeuvres (emergency braking, rapid lane changing etc.). This information, linked to real world occupant photographic studies, gives indications of real world postures at impact that can be considered for smart restraint systems.

A total of 49 volunteers were driven in an instrumented test car and were subjected to fierce pre-impact manoeuvres without warning. Each volunteer undertook 3 tests over a period of time either from their own normal postures, from pre-defined postures, or whilst undertaking various tasks.

Project staff, aware of the tests and in control of the severity and the frequency of the tests, undertook higher risk tests including unbelted and extreme out of position tests. Also 6 crash test ATDs of different sizes were subjected to the same vehicle manoeuvres, so that their inertial behaviour could be compared with human behaviour. In all, 230 tests were undertaken, with each test being filmed from 5 on-board cameras.

The development of the test methodology is described and the drawbacks of the earlier concepts are explained, together with the improvements made. The strengths and limitations of the tests and results are also explained.

Following a discussion of the results, a number of conclusions have been drawn, regarding both human behaviour and the strengths and limitations of using crash ATDs for pre-impact work. These conclusions have implications for managing occupant postures at the commencement of impact events.

INTRODUCTION

Many of the occupant restraint systems fitted to European road vehicles only react when there is a crash and mitigate injuries in a fixed or limited manner. Some of the more modern systems have improved functionality and can "tune" their response to suit a range of variables. These may include: impact severity, occupant weight and occupant fore/aft position. Such adaptive restraints are sometimes known as "smart restraints" and most are developed to meet the US requirements of FMVSS208, in the absence of any European equivalent. Vehicle manufacturers may have their own standards in addition, but are generally considered to be based upon FMVSS208.

Restraint systems are developed around certain recognised occupant sizes, these being 5th%ile female, 50th%ile male and 95th%ile male and sometimes child ATD's. ATDs and computer models exist that facilitate this work. However, consideration should be given to the proportions of the population outside these sizes.

Restraint systems are often checked to ensure that the occupant (ATD) is not injured if the restraint system is deployed whilst the occupant is Out Of Position (OOP). A very wide range of "OOP" tests are used by the industry but little information is readily available regarding the incidence of such postures in general driving and in accidents, so prioritisation of such tests can be difficult. Anecdotal evidence and casual observation have shown that some occupants can and do adopt particularly extreme postures, such as passengers with their feet on the facia and children standing in front of the front seat passenger (Bingley et al 2005). These cases are rarely considered by the manufacturers. Accident data can give good indications of injuries sustained in specific cases, eg. CCIS (Ref. 2) and GIDAS (Ref. 3), however, it is unusual that the pre-impact posture is known or can be determined.

Typically in development programmes, there is little consideration given to pre-impact vehicle manoeuvres (such as pre-impact braking) and the resulting occupant motion from their “normal” seating position. Although some research has been undertaken by TRW (Ref. 4) on a range of volunteer drivers and by Autoliv (Ref. 5) on a single volunteer passenger, understanding in this area is still quite limited.

It is generally considered that ATDs are not good indicators of human behaviour during the pre-impact phase, as they do not respond to stimuli and do not adopt “bracing” responses.

The first work package of the PRISM project provides new and extended data in this field to assist in the development of smart restraint systems.

Photographic Studies

The initial stage of the occupant posture work was a photographic study, as detailed in the written paper “Determination of Real World Occupant Postures by Photo Studies to Aid Smart Restraint Development” (Ref. 6, paper 05-0319, Bingley). The objective of this study was to determine how occupants sit in vehicles on the roads of Europe. A total of over 5000 samples were taken from 6 test sites across Europe. These samples were analysed to determine occupant longitudinal, lateral and upper limb locations. Other potentially useful data, (child occupancy, luggage location etc) were also collected. The results from this work provided statistical information on real postures that may be considered as “pre-event” start positions – inputs for this study (Table 1).

Passenger Response Studies - Overview

A total of 49 volunteers, 4 MIRA project staff and 6 ATDs undertook a range of tests, totalling 230 in number. A range of pre-impact manoeuvres events were undertaken and the occupants were encouraged to adopt various postures before the events took place. Most of the volunteers were unaware of the nature of the tests to ensure realistic responses. The ethical issues were also considered and the ethical guidelines of the British Psychological Society were followed. One of the results of this was to ensure that the higher risk tests (including unbelted) were only undertaken by project staff in strictly controlled safety conditions. The test vehicle was instrumented and carried a range of on-board video cameras to allow later assessment of the passenger behaviour.

Table 1.
Test Postures (Selected From Photo Studies)

Volunteer Posture (Not Aware of Event)
Normal (Own) Position
FMVSS 208 ATD Equivalent Position
Looking in Vanity Mirror
Dash Control Adjustment (Radio)
Arm on Waist Rail
Arm on Arm Rest
Holding Roof Grab Handle
Arm Out of Window
Holding Head Restraint (both hands)
Holding Magazine, Legs Crossed, On Phone
MIRA Staff Posture (Aware of Event)
Reaching into Footwell
Adjusting Seatbelt
Drinking / Eating
Sitting on Foot / Feet
Turning to Talk to Rear Seat Passengers
Unbelted
ATD Posture
HIII 95th %ile Male - normal
HIII 50th %ile Male - normal
HIII 5th %ile Female - normal
HIII 6 Year – normal (No child seat)
HIII 3Year – Held Standing Between Passenger Legs
CRABI – Held in Passengers Arms

The test programme matrix was determined from the postures selected from the photographic studies (Table 1) and with a range of vehicle motions (Table 2).
Risk assessments for the tests were also undertaken.

Table 2.
Vehicle Manoeuvres (Simulating Pre-Impact)

Straight line emergency braking
Rapid lane change (sudden right, then left, as if to avoid an oncoming vehicle)
Rapid lane change, then emergency braking
Rapid direction change followed by a lift-off over steer (resulting in a spin or a partial spin, as if out of control before sliding into a tree)
Rapid direction change followed by an opposite direction change (as if driving fast down a sweeping road)

METHODOLOGY

Test Rationale

In this work, the basic rationale was that under extreme stress or perceived danger, basic human survival instinct would dominate and in general, passengers would react in the same way under similar test conditions.

The primary assumptions were that the passengers would react to the vehicle motion, the sudden braking etc. Although the tests would be carried out on a proving ground, it was considered that the tests would be sufficiently realistic to obtain valid occupant reactions. In the event however, other factors proved to be dominant and additional controls had to be put in place to obtain acceptable results.

Test Facilities

The tests were undertaken at MIRA Ltd. in Warwickshire, UK. The test track selected was the handling circuit. The circuit is a closed, single user facility with a number of potential routes and the direction of travel is totally free. The surface is a very high grip material called "Delugrip" which allows for extremely high deceleration levels and cornering speeds. The circuit has an office close by for briefing and de-briefing of volunteers.

In general, the test vehicle was driven around the circuit in a clockwise direction and various vehicle manoeuvres were undertaken at suitable points around the track.

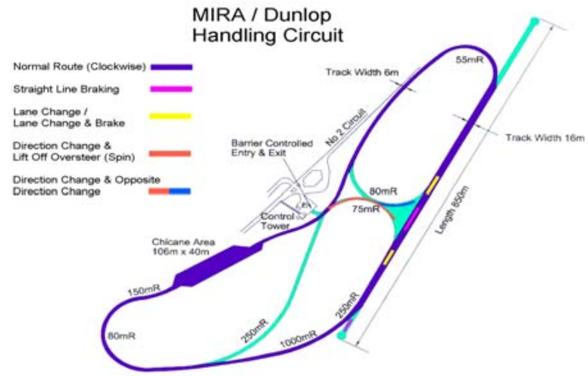

Figure 1. The MIRA Handling Circuit

The Test Vehicle

The test vehicle was a RHD 5-door Ford Focus (Figure 2). It was selected since it represents the medium hatchback size popular across Europe and it was available at MIRA during the scheduled test period. The airbag system was disabled for safety, in case it should deploy when the volunteers were in close proximity.

The vehicle was fitted with 5 cameras, longitudinal and lateral accelerometers and a data logging system. The ethical constraints meant that it was necessary to declare to our volunteers that they may be filmed, but it was not intended that the cameras affect the passenger behaviour, so they were hidden as much as possible. Two of the cameras could not be hidden, but were placed out of the passenger's line of sight. As a result, the semi-concealed cameras were rarely noticed and the novelty of the testing and the environment and the deliberate distractions ensured that the volunteers quickly forgot that they were being filmed.

Figure 2. The Ford Focus Test Vehicle

The five cameras fitted were arranged to provide the optimum views of the volunteer passenger. Miniature cameras were installed forward of the passenger's head whilst the larger cameras were positioned behind.

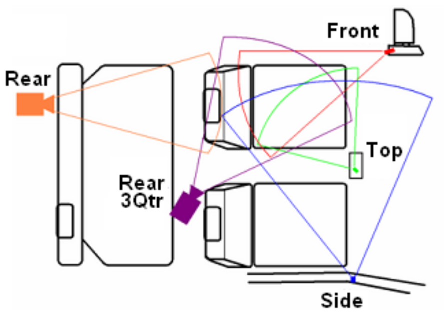

Figure 3. Diagram showing positions of the 5 cameras and their fields of view

The front miniature camera was mounted in the passenger door, in the panel surrounding the door mirror adjuster giving a frontal view of the volunteer. (Figure 4.)

Figure 4. Showing the front camera location and a sample of the camera output.

The top camera was mounted in the roof, concealed in the overhead lamp. This gave an overhead view showing position of the hands and giving information about the foot position (Figure 5).

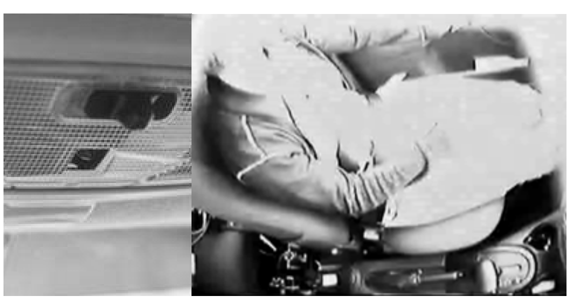

Figure 5. Showing top camera location in the map lamp and a sample of the camera output.

The side camera was mounted in the opposite A-pillar trim and provided a lateral view, giving a clear indication of forward motion of the occupant and proximity to the airbag module (Figure 6).

Figure 6. Showing the side camera location on the A-pillar and a sample of the camera output.

A pair of video cameras were also fitted to the vehicle, one behind the passenger, giving a rear view, showing head lateral position and one mounted off the rear of the driver's head restraint, giving a rear ¾ view (Figure 7). These were supported on rigid brackets.

The miniature cameras were lower resolution and had limited dynamic range, so the quality of some of the images was not ideal. The larger cameras with image stabilisation and audio data, provided further insight into the passenger's behaviour.

In addition to the cameras, and the accelerometers, a brake pedal force transducer was also fitted, together with a twin display, showing longitudinal acceleration and brake pressure for the driver. These are just visible in Figure 6.

Figure 7. Showing the rear and rear ¾ cameras, mounted on their brackets and sample views from each.

Test Procedure Outline

Most of the postures were considered to be low risk and so were safe enough for the volunteers to undertake without any type of warning. Some postures were considered too hazardous for the volunteers, but were acceptable if undertaken by project staff who understood the risks and controlled the severity of the test by instructing the driver. Some tests were considered to be too dangerous to be undertaken at all. These included: feet on fascia, drinking from a glass bottle and sleeping fully reclined whilst belted (strangulation hazard).

It was suggested that only 3 tests could be given to each volunteer before they began to suspect the reason for the test and then possibly change their behaviour. It was intended to have 50 volunteers, giving 150 possible tests. The intention was that each test would be performed several times with different volunteers to show consistency, so the total range of tests had to be limited.

Volunteers who had completed the tests were isolated from those that had not, to ensure that no "pre-warning" of events was given. A MIRA researcher was present in the rear of the vehicle to run the data-logger and to advise the volunteer of the postures required. In the early tests, a number of settling in laps were undertaken to relax the passenger so that they were less prepared for the violent pre-impact manoeuvre. Also there were a number of laps between each test for the same reason. All events were undertaken from a test speed of 50mph (80.5kph)

Although each volunteer was asked to adopt a posture, their interpretation of the posture varied, and in some cases, the posture was actually impossible (especially large male occupants who could not cross their legs above the knee). Where the volunteer adopted an unexpected posture, or misunderstood, they were not corrected (unless they asked if it was correct). This allowed the posture to be as natural as possible for the volunteer.

Methodology Development

Initial test procedure - The volunteer passengers were made aware that the driver was a MIRA professional driver. Events were undertaken in random order, but within the following schedule:

1) Briefing session
2) Lap 1 = Warm – up / settle passenger
3) Lap 2 = Warm – up / settle passenger
4) Lap 3 = Event 1
5) Lap 4 = No activity – to settle passenger
6) Lap 5 = Event 2
7) Lap 6 = No activity – to settle passenger
8) Lap 7 = Event 3
9) Return for debrief session

The methodology was altered during the testing when the early results became apparent. Some of the assumptions made regarding occupant behaviour proved to be incorrect. In particular, the volunteer's responses were affected by the many safety measures that were evident. These measures included:

- The knowledge that the driver was a professional test driver.
- The necessary process of explaining the safety aspects risk assessments and obtaining signed consent during the briefing session.
- The knowledge that the test track was a safe, test environment with wide run-off areas.

This lead to many of the volunteers assuming an un-naturally relaxed attitude, happily and confidently accepting the vehicle sliding and spinning around and treating the experience in a similar manner to a fairground ride.

Since the second and third points were difficult or impossible to work around, it was decided to modify the volunteer passengers perception of the driver.

Final test procedure A fake "driver volunteer programme" was conceived and the professional driver acted as though he was one of several volunteer drivers on this project, though this run "was his first time here at MIRA" The driver also engaged the passenger in conversation about his (bogus) job as a plumber and how he was not used to driving automatic transmission vehicles. This, together with very detailed instructions on how to drive around the track convinced all the volunteers, although some started to suspect the truth after some of the tests. Events were undertaken in the following specified sequence:

1) Briefing session
2) Lap 1 = Warm – up / settle passenger, “accidentally” over-shoot end of main straight and undertake emergency Straight Line Braking.
3) Lap 2 = Gentle Lane Change or Lane Change & Brake on main straight.
4) Lap 3 = Violent Lane Change or Lane Change & Brake on main straight.
5) Lap 3 = Direction Change or Direction Change and Lift-Off Oversteer (Spin) at end of lap.
6) Lap 4 = A half lap to return to the briefing room
7) Debriefing session

Clearly, the level of sophistication of the subterfuge was important, so a more detailed explanation of the final methodology is given below:

Lap 1 The driver was instructed to drive around the circuit at “the speed at which he felt comfortable” – which was actually gradually built up to achieve 50mph along the main straight. The passenger was asked to adopt their first posture, or not, depending if their natural posture was required.

At the start of the main straight, the confusing instruction was given to “turn right at the end of the straight”. The actual turning was just before the end of the straight so the driver deliberately overshot it and had to brake hard (straight line braking) to avoid the concrete barrier at the extreme end of the straight. The reactions from the passenger were marked – appearing to believe that the driver might crash into the barrier.

One of the volunteers with automotive industry experience realised that the braking was too good – the driver did not lock the wheels and stopped the vehicle impressively quickly and this raised some doubts. Most passengers accepted the story, many suggesting that he should be careful and not to worry about his “mistake”. The driver then continued round to start the second lap.

Lap 2 At the start of the main straight, the passenger was asked to adopt their second posture and the driver was asked to “weave gently from side to side”, sometimes with the instruction to come to rest gently afterwards. This is what the driver did and then carried on round to start lap 3.

Lap 3 At the start of the main straight, with the passenger still in their second posture, the driver was asked to repeat the weave from the previous lap “just a little more vigorously”. In fact, the driver undertook the weave and, if required, the braking, very violently, at the limit of adhesion of the vehicle. (Lane Change or Lane Change and Brake) After “recovering” from this, the driver apologised to the passenger, explaining that the power steering and the brakes were much more sensitive than he was used to! The volunteer passenger was then asked to adopt the third (and final) posture as the driver started round to start the fourth lap.

Lap 4 Since the main test manoeuvres had taken place on the broad main straight, the volunteer was expecting the driver to continue around the main outer circuit again as instructed. However, on the entry to the start of the fourth lap, the driver swerved right without warning to enter the centre section of the track, followed by either a swerve to the left or by putting the vehicle into a spin (Lift Off Over-steer). This surprised all volunteers and confused most, though some (almost exclusively the male volunteers) initially realised the truth. The majority of female volunteers still believed the false credentials of the professional driver up until the experimental debriefing.

The debriefing explained the testing and its purpose within the project and the volunteers were monitored for any signs of ill health or sickness. In fact no volunteers reported feeling unwell after the tests.

RESULTS

General Notes

The work produced large amounts of data in various forms, especially video. To date analysis of the results has been limited to identify trends and concepts to assist in the selection of critical scenarios within next stage of the PRISM project.
In total, 230 tests were undertaken, usually with 5 video clips per test. The video clips collected consist of a 3 second period before the initiation of the event, through to a “steady state” conclusion, when the event can most definitely be considered to be over. Typically, each video clip duration was between 10 and 15 seconds.

The results are split into 3 basic sections:
- Bracing incidence, using volunteer and some staff data.
- Higher risk “Out of Position” tests.
- ATD tests.

For the ATD tests simple comparisons with similar occupant tests have been made. The types of tests and the distribution of postures and vehicle motions are shown in the following figures.

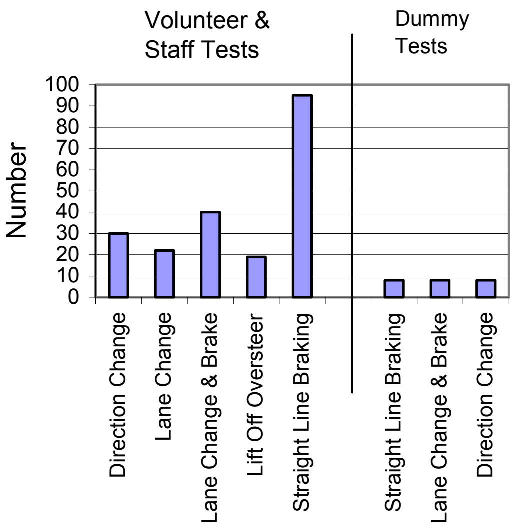

Figure 8. Vehicle Test Manoeuvre Distribution

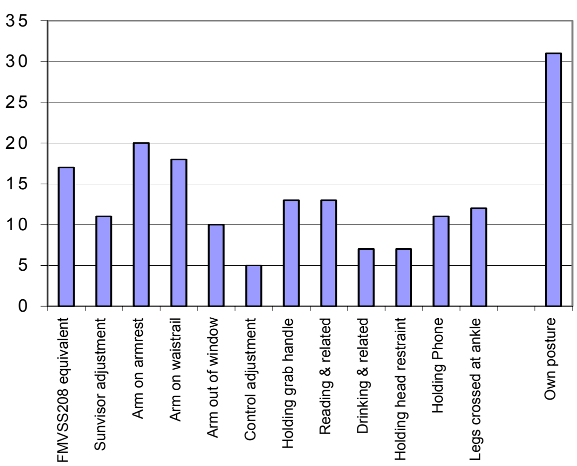

Figure 9. Volunteer Postures

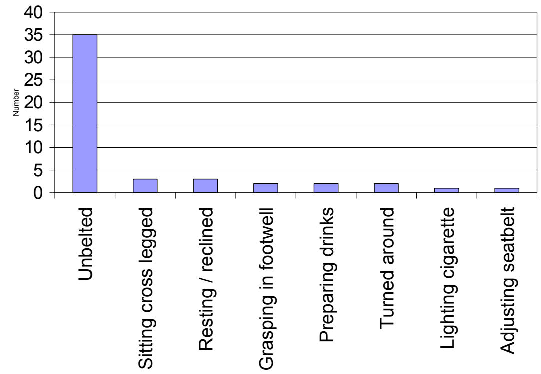

Figure 10. High Risk Postures

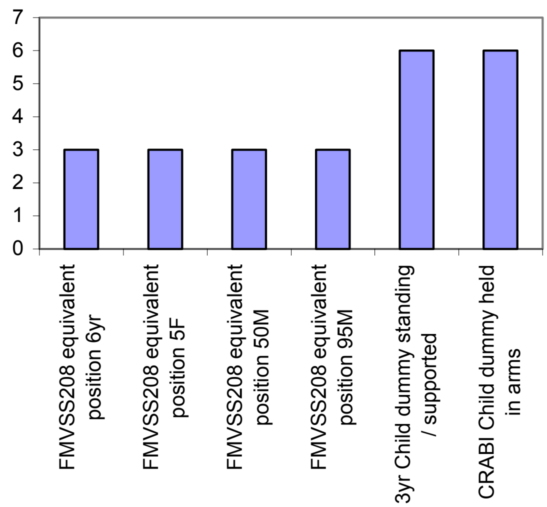

Figure 11. ATD Postures

The vehicle motions were determined by accelerometers fitted in the centre of the vehicle. The data was not corrected for vehicle pitch & roll.

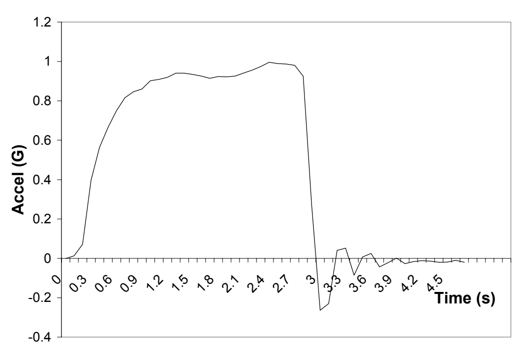

Figure 12. Straight Line Braking – Typical Vehicle Acceleration

OVERVIEW OF RESULTS & OBSERVATIONS

Bracing Incidence

The general trends discussed next are taken from the volunteers and the MIRA staff tests, with some test induced exceptions (unbelted tests etc.) where these clearly distorted the trends. The perceived levels of the validity of the tests varied depending on the confidence of the test subject. The data shown in the next section was taken only from clearly valid tests. Results were analysed by viewing the video clips and identifying reactions and limb motions. The wide range of potential limb locations were simplified for statistical purposes, concentrating on "bracing" behaviour.

Arm (and hand) locations were considered as :

- Full bracing : Hand holding on to firm structure
- Part bracing : Arm resting against firm structure or hand holding seat cushion
- Task occupied : Hand is holding an object or undertaking a non-bracing task
- Other : Generally hand on lap
- Aborted bracing : Clear case of a bracing action started, but aborted – hand remains in space.

The tables below summarise the results by vehicle manoeuvre.

Table 3.
Arm Location - Straight Line Braking

Left Arms			Right Arms		
Initial Position	**Final Position**	**Qty**	**Initial Position**	**Final Position**	**Qty**
Full Bracing	Full Bracing	7	Full Bracing	Full Bracing	
Part Bracing	Full Bracing		Part Bracing	Full Bracing	
	Part Bracing	2		Part Bracing	1
	Aborted Bracing			Aborted Bracing	
Task Occupied	Full Bracing	1	Task Occupied	Full Bracing	
	Part Bracing			Part Bracing	
	Task Occ.			Task Occ.	1
	Other			Other	2
Other	Full Bracing	3	Other	Full Bracing	1
	Part Bracing			Part Bracing	3
	Aborted Bracing	2		Aborted Bracing	2
	Other	3		Other	8
Some Bracing Effect = 72%			**Some Bracing Effect = 28%**		
Increased Bracing Effect = 22%			**Increased Bracing Effect = 22%**		

Table 4.
Arm Location – Lane Changing

Left Arms			Right Arms		
Initial Position	**Final Position**	**Qty**	**Initial Position**	**Final Position**	**Qty**
Full Bracing	Full Bracing	4	Full Bracing	Full Bracing	
Part Bracing	Full Bracing	1	Part Bracing	Full Bracing	
Task Occupied	Full Bracing	1	Task Occupied	Full Bracing	
	Task Occupied	1		Task Occupied	2
Other	Full Bracing	3	Other	Full Bracing	
	Part Bracing			Part Bracing	4
	Other			Other	4
Some Bracing Effect = 90%			**Some Bracing Effect = 40%**		
Increased Bracing Effect = 50%			**Increased Bracing Effect = 40%**		

Table 5.
Arm Location – Lane Changing & Braking

Left Arms			Right Arms		
Initial Position	**Final Position**	**Qty**	**Initial Position**	**Final Position**	**Qty**
Full Bracing	Full Bracing	5	Full Bracing	Full Bracing	
Part Bracing	Full Bracing	1	Part Bracing	Full Bracing	
Task Occupied	Full Bracing	2	Task Occupied	Full Bracing	
	Part Bracing	2		Part Bracing	1
	Task Occupied	3		Task Occupied	7
	Other			Other	1
Other	Full Bracing	2	Other	Full Bracing	1
	Part Bracing			Part Bracing	4
	Other	2		Other	3
Some Bracing Effect = 71%			**Some Bracing Effect = 35%**		
Increased Bracing Effect = 41%			**Increased Bracing Effect = 35%**		

Table 6.

Arm Location – Direction Change & Lift Off Over Steer

Left Arms			Right Arms		
Initial Position	Final Position	Qty	Initial Position	Final Position	Qty
Full Bracing	Full Bracing	2	Full Bracing	Full Bracing	
Part Bracing	Full Bracing	3	Part Bracing	Full Bracing	
	Part Bracing			Part Bracing	1
Task Occupied	Full Bracing	1	Task Occupied	Full Bracing	
	Task Occupied			Task Occupied	3
Other	Full Bracing	1	Other	Full Bracing	
	Part Bracing	2		Part Bracing	6
	Aborted Bracing			Aborted Bracing	1
	Other	0		Other	
Some Bracing Effect = 82%			Some Bracing Effect = 64%		
Increased Bracing Effect = 64%			Increased Bracing Effect = 55%		

Leg and foot locations were considered as

- Rearwards : Tibia to femur angle <= 90 degrees
- Mid : Foot on floor, tibia to femur > 90 degrees
- Forwards : Foot on toe-board / leg near straight.

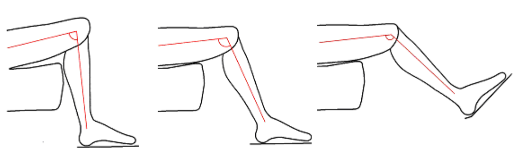

Figure 13. Leg / Foot Location Options

Table 7.

Leg Location – Straight Line Braking

Left Legs			Right Legs		
Initial Position	Final Position	Qty	Initial Position	Final Position	Qty
Rear	Rear	27	Rear	Rear	21
	Mid	5		Mid	6
Mid	Mid	26	Mid	Mid	30
	Forward	1		Forward	1
Crossed	Crossed	1	Crossed	Crossed	1
Leg Brace Movement Forward = 10%			Leg Brace Movement Forward = 13%		

Table 8.

Leg Location – Lane Changing

Left Legs			Right Legs		
Initial Position	Final Position	Qty	Initial Position	Final Position	Qty
Rear	Rear	2	Rear	Rear	2
	Mid	3		Mid	2
Mid	Mid	4	Mid	Mid	5
	Forward	0		Forward	0
Forward	Forward	1	Forward	Forward	0
Crossed	Crossed	0	Crossed	Mid	1
Leg Brace Movement Forward = 30%			Leg Brace Movement Forward = 30%		

Table 9.

Leg Location – Lane Changing & Braking

Left Legs			Right Legs		
Initial Position	Final Position	Qty	Initial Position	Final Position	Qty
Rear	Rear	7	Rear	Rear	6
	Mid	1		Mid	2
Mid	Mid	8	Mid	Mid	6
	Forward	1		Forward	0
Crossed	Mid	0	Crossed	Mid	2
	Crossed	0		Crossed	1
Leg Brace Movement Forward = 12%			Leg Brace Movement Forward = 24%		

Table 10.

Leg Location – Direction Change & Lift Off Over Steer

Left Legs			Right Legs		
Initial Position	Final Position	Qty	Initial Position	Final Position	Qty
Rear	Rear	6	Rear	Rear	5
	Mid	0		Mid	1
Mid	Mid	3	Mid	Mid	3
Forward	Forward	0	Forward	Forward	1
Crossed	Mid	1	Crossed	Mid	0
	Crossed	1		Crossed	1
Leg Brace Movement Forward = 9%			Leg Brace Movement Forward = 9%		

Extreme Out Of Position Tests

Holding Objects - The stability or motion of an object held appears to depend on 3 factors:

- The mass of the object.
- The strength of the passenger.
- The degree of extension of the shoulder and elbow joints.

The first and second of these factors were expected unlike the final point. It was quite possible for a small female passenger to hold the CRABI ATD against her chest during braking, (Figure 14) but was almost impossible for a large male to hold a full water bottle whilst drinking – moved away from the mouth and towards the airbag and a possible projectile hazard in the event of airbag firing (Figure 15). Similarly with the standing 3 year H3 ATD – whose head hit the dash panel, (Figure 16).

Figure 14. Holding CRABI ATD

Figure 15. Holding Water Bottle

Figure 16. Holding 3Year H3 ATD

Reaching Into Footwell - If extreme braking is undertaken whilst the passenger is in this position the natural reaction is to raise the head up to see the problem, (Figure 17). If the reaching activity is incomplete, the passenger may keep their hand(s) locked in whatever position it is in. Alternatively, the passenger may put a hand against the facia to push back towards the seat.

Whichever action occurs, the "peep" over the facia exposes the head and, in particular, the neck, to increased risk of injury from the passenger airbag.

Figure 17. Reaching into Footwell

Lying in Fully Reclined Seat - The passenger is unlikely to be aware of any impending vehicle manoeuvre. Severe submarining under the lap belt occurs with little restraint. The diagonal belt is in minimal contact (Figure 18). Virtually all occupant restraint is obtained by heavy knee or lower leg contact to the dash panel or glove box lid. Upon impact with the glovebox the passenger is stable under braking acceleration loads.

Figure 18. Fully Reclined

Turning Around To Rear Seat Passengers - The front seat passenger is restrained by the diagonal belt around the neck. The occupant does not tend to react other than to "freeze" in position. The occupant trajectory is unlikely to cause any problematic airbag interaction in itself but the belt loads on the neck could be considerable and painful under extreme braking (Figure 19). The additional loads caused by pre-tensioners and then by the crash deceleration could be a significant risk in this case.

Figure 19. Turning Around

<u>ATD / Volunteer Comparison Tests</u> - A series of ATDs were evaluated in similar test conditions to the volunteers. The ATDs used were : H3 5^{th}%ile female, H3 50%ile male and 95^{th}%ile male.

Figure 20. Comparison Of 5^{th} Female H3 ATD With Small Female Passenger

Summary

Figure 20 shows that ATDs and human volunteers behave differently in similar straight line braking conditions. Points to note include:

- ATD torso has limited motion: buttocks remain very close to start position and upper torso rotates forward slightly.
- Human torso has more motion: buttocks slide forward more and upper body motion is exaggerated by more rotation around the diagonal belt (especially in this case with hand bracing)
- ATD head flops forward, rotating head and neck downwards; hence the gap under the chin to chest decreases with forward motion.
- Volunteer head is held upright, eyes remain level, to retain forward vision; hence the gap under the chin to chest increases with forward motion.
- The feet of the ATD did not slide forward under braking and in this respect, showed some similarity to the human volunteers.

Figure 21. Comparison of 95^{th} Male H3 ATD With Large Male Passenger

Figure 21 shows that ATDs and human volunteers also behave differently in lateral accelerations, in this case similar violent lane change manoeuvres.
The centre images show the maximum lateral displacement during a swerve to the right. The lower images show the locations of the ATD and volunteer immediately after the swerve back to the left. The displacements are now totally different, but this represents the maximum lateral displacement point of the ATD. Points to note include:

- The ATD has particularly broad shoulders, limiting lateral motion compared to the volunteer.
- In the first manoeuvre, the ATD torso remains linear and the whole torso rotates about the buttocks.
- The volunteer spine describes a curve, so whilst the body weight is transferred to the

outer buttock like the ATD, the shoulders remain relatively level.

- The ATD head moves outboard but there is no noticeable neck bending.
- The volunteer head is held inboard, following the lateral curve of the spine, maintaining the eyes near level and retaining the field of vision.
- During the second manoeuvre, the ATD torso swings across, the buttocks remain in approximately the same location but weight is transferred to the inner buttock. Obviously there is no bracing action. The seat belt fell from the shoulder.
- The volunteer lower torso appears to have far greater lateral motion inwards, with the spine curving the opposite way but to a lesser extent. As before, the shoulders remain relatively level.
- The ATD head moves inboard and again, there is no noticeable neck bending.
- The volunteer head is held near seat centreline, following the lateral curve of the spine, maintaining the eyes near level and again, retaining the field of vision.

The ATD and volunteer postures are now different.

DISCUSSION

General Observations

Based on the results of this study front seat passengers do not tend to move their legs during pre-impact events. However, in instances where this did arise it was generally found that they move one leg forward (and occasionally outwards in lateral events).

In shorter duration events, such as Straight Line Braking, the level of leg bracing motion is low (~10%).

In the longer duration events or events where the acceleration direction changes, there is some more leg bracing motion (~20%).

In the long duration lateral loading events with no acceleration reversal, the proportion of leg bracing motion is low (~10%).

Since the test car was RHD, the passenger left hand was used more often for bracing against the door fitments.

Of the 31 "own posture" tests, only one had any bracing, which was partial with one arm. Many of the "requested" postures involved some sort of bracing with left arm/hand, resulting in a distortion of the bracing figures upwards.

There appeared to be a lower incidence of bracing increase in the shorter duration pre-impact events (Straight Line Braking).

Longitudinal Stability - A very clear and important observation from the work is that longitudinal stability for a belted occupant is heavily dependent on leg and foot location.

Bracing using arms and hands seems limited unless the passenger is already holding onto some firm structure (seat, roof grab handle, arm rest, etc.) in which case the grip tightens.

In some cases, if a firm structure is a short distance from the hand, timescales permit and the individual is sufficiently motivated, they may reach for this but sometimes the reaching motion is aborted if the diagonal belt halts the torso motion.

If both feet are forward, slightly splayed and the knees near locking point, the stability provided to the pelvis is very high. This reduces as one or both legs are brought rearwards. It would appear that one leg well braced is generally sufficient for severe emergency braking but two are better. It would also appear that one leg well braced forward is generally better than two partially braced, though more work is needed to confirm this hypothesis.

Lateral Stability - Lateral stability for a belted occupant also appears to be affected by foot position. A wide placement provides a degree of pelvis restraint, and once again, this appears better if the knees are near locked. There is very little control for the upper body however. All bracing effects are far less pronounced than for frontal decelerations. A narrow or rear foot position provides virtually no lateral motion control to the pelvis.

There is generally insufficient time to react with hands unless they are already holding the seat, door, grab handle or some other structure, so upper body motion control is almost non-existent. There is also minimal seatbelt influence with the belt type fitted to this test vehicle.

Generally inertial behaviour dominates the occupant motions in violent lateral movement, so occupant response is largely unimportant. If several cycles of reversing lateral acceleration allow sufficient cumulative time the passenger may find a suitable structure against which they may brace themselves. This was observed in one case but the motions and interactions were extremely complicated and it would appear that further work in this area would be of limited value.

Pre-Impact Braking – The Four Primary Cases

From the observations of the volunteer and the project staff tests four primary cases of importance have been identified for passenger trajectories during pre-impact braking:

Belted Occupant With Legs Braced - The occupant's braced legs prevent or limit pelvis motion significantly. This may be influenced by seat design to some degree, although it is difficult to ascertain from this project. The occupant loads the diagonal part of the seatbelt and "hangs" against it after a limited amount of upper torso motion, (Figure 22). Generally, no hand bracing is required, so if the occupant is holding an object etc., he continues to do so. If one or other hand is already bracing or is so close to bracing that contact is made this may reduce forward displacement of the upper torso slightly. However, the amount is not great compared to the effect of the diagonal belt.

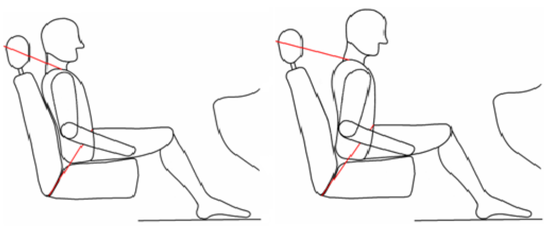

Figure 22. General Motion Of Belted Occupant With Braced Legs

Belted Occupant, Legs Not Braced - The occupant's un-braced legs do not appear to prevent or limit pelvis motion to any significant extent.

The occupant loads both the diagonal and lap parts of the belt and "hangs" against both (Figure 23). A more equal loading (than the legs braced condition) means that the torso remains more upright. Again, no hand bracing is required, so if the occupant is holding objects etc, he is likely to continue to do so. Again, if one hand is already bracing this is likely to reduce forward displacement of the upper torso slightly.

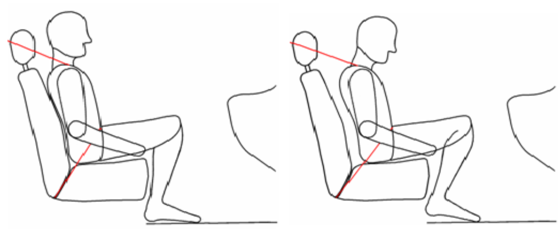

Figure 23. General Motion Of Belted Occupant With Legs Not Braced

Unbelted Occupant, Legs Braced - If the unbelted passenger is subjected to moderate to severe braking forces (up to about 5m/s/s) his braced legs may prevent pelvis motion, but are unlikely to prevent it at higher deceleration levels (above 5m/s/s) with typical seat / clothing friction. Knee impacts are unlikely except from high speeds with high decelerations or very close initial positions. Substantial upper body motion occurs and the occupant will have a definite tendency to put out hands to the dash to brace for impact at higher deceleration levels (above approx 4m/s/s). If one or other hand is already bracing this is likely to reduce forward displacement of the upper torso, possibly with yaw rotation. No unbelted trials were made with hands already occupied so that the conflict between hand bracing and continuing to hold the object was not investigated.

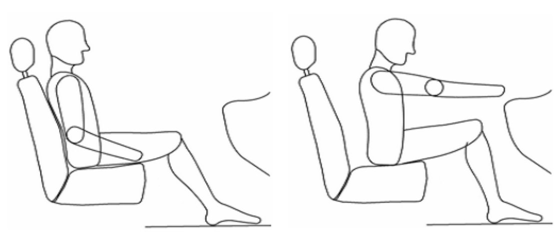

Figure 24. General Motion Of Unbelted Occupant With Legs Braced

Unbelted Occupant, Legs Not Braced - The unbraced legs of an unbelted passenger do not prevent rapid pelvis motion, with knee impact to the lower dash occurring relatively early, even at lower deceleration rates. As the femurs tend to point upwards and forwards slightly, and given the centre of mass of the body is near the pelvis, this impact condition can be quite stable, not requiring any hand bracing for stability, even though the event is so rapid that there is probably insufficient time to move the hands to the correct position, (Figure 25).

At higher decelerations a second motion begins to occur with the whole upper body rotating forwards and upwards about the knee impact point. The head and face can rapidly approach the header rail and the upper windscreen. By now there may have been sufficient time to deploy the hands to brace against the facia. This case could be important for upper torso, head, neck and hand injuries caused by a deploying passenger airbag. Ejection or partial ejection through the windscreen may also be a risk. Knee bolster airbag deployment during knee contact may also cause additional injury or promote further occupant trajectory problems.

Figure 25. General Motion Of Unbelted Occupant With Legs Not Braced

Influencing Factors on Behaviour

The test work has shown that a wide variety of factors can affect the posture of the passenger. Some of these factors we envisaged before commencement of the test work, others were not. The influence of some of the other factors was seen to be problematic and attempts were made to control these. However, this was not possible for all of the factors identified.
In an attempt to explain the various factors a schematic plan has been developed within the project. This is explained in more detail in the full report on the PRISM website (Ref 7.). In summary, the posture at impact can be considered to be the result of three phases: The first phase is the "General Posture" of the passenger, possibly modified by some pre-event activity, to give a second phase "Instantaneous Pre-Event Posture". This in turn may be modified event inertial or reaction effects to give the final phase "Instantaneous Pre-Impact Posture". These phases and the factors that affect them are described in more detail in the full report.

CONCLUSIONS

At the start of the testing the test methodology was not particularly realistic. This improved as the tests progressed. The final volunteer tests appeared more believable. It is believed that none of the volunteers acted for the cameras but their state of mind regarding their personal safety played a larger role than expected.
The following points have been determined as the most significant:

Pre-Impact Braking

Occupant trajectory during pre-impact braking is most heavily influenced by 2 pre-event factors:
- Seat belt use (or non-use)
- Foot location, especially of the most forward foot.

Bracing effects may be summarised:
- The longer the duration of the pre-impact event the more likely any bracing effect is to be undertaken.
- Changing of leg positions occurs in a minority of cases and then only one leg, always forwards.
- Bracing with arms and hands occurs in a minority of cases when belted and is most likely if already holding or close to holding a firm structure, such as the door.
- If the passenger is holding an object or is engaged in some task they tend to remain "frozen" mid task until the event is over.
- If holding an object of significant weight or not close to the body, the object's inertia will carry it forward towards the dashboard.
- The influence of bracing is greater if no seat belt is worn, when trajectories differ, especially at higher deceleration levels.

Pre-Impact Direction / Lane Change

- Occupant trajectory in violent lateral accelerations is almost entirely inertial in the initial phase.
- The head and neck tend to be maintained upright and level allowing field of vision to be maintained.
- During the first phase arm/hand bracing often occurs to prepare for the reverse acceleration.
- After the first phase some lateral leg bracing may occur if some further lateral motion is expected.

Extreme Out Of Position Tests

Each of the scenarios considered has its own hazards and problems. Each scenario should be considered based on likely incidence (from the photographic studies, or similar), risk of injury (from modelling work) and from likely cost of applying a suitable mitigating technology.

ATD Tests

The ATDs appeared to bear little similarity to the human volunteers. The adult ATDs have very stiff spines that limit motion in high acceleration cases and the lack of neck muscles frequently put the head in the wrong location and attitude. The lack of bracing means that the similarities with human volunteers reduce as the pre-impact event time increases.

Other Observations & Conclusions

It was also noted that a very wide range of variables affect a passenger's posture before and during a "pre-impact" event. The test methodology was modified to minimise the effects of unwanted variables. A general overview of all the factors and variables is given in the main report to assist in understanding the scope of the subject for further work.

ACKNOWLEDGEMENTS

PRISM is a DG Research project under the 5th Framework, G3RD-CT-2002-00848.

Thanks to all the individuals who participated in this work. This includes the project partners: MIRA (coordinators), CIDAUT, Daimler Chrysler, DalphiMetal, TNO, TRL, TRW, TUG & VSRC.

The support and assistance of the volunteers is also acknowledged. Further details are given in the report from which this paper is derived, together with other related reports on the PRISM web site at : http://www.prismproject.com.

REFERENCES

1) Couper G J and McCarthy M G, "The Effect Of Driver Positioning On The Dynamic Response To A Potential Accident Event" TRL Ltd. IRCOBI Graz, Austria, September 2004.

2) CCIS website – http://www.ukccis.org/home.htm

3) GIDAS website - http://www.gidas.org/

4) Franco Zuppichini, Dante Bigi, Ermanno Bachi, Andrea de Adamich, (TRW) "How Drivers Behave in pre-impact Emergency Situations". IRCOBI – Hannover, Sept.97

5) Markus Kümpfbeck, Detlev Oertel, Klaus Pilatus, (AutoLiv) "Occupant Kinematics During Emergency Braking". IRCOBI Sitges, Spain Sept.99

6) Bingley L, Morris R, Cross G, "Determination of Real World Occupant Postures By Photo Studies To Aid Smart Restraint Development", 19th ESV, Washington 2005.

7) Morris R, "Occupant Behaviour During Pre-Impact Braking – Car Passengers" Report R4C, PRISM website: http://www.prismproject.com.