Technical Report: Observation technologies for drivers with restricted head or trunk movement

by T Luke, C Inwood, and R Hutchins
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Observation technologies for drivers with restricted head or trunk movement
Client: Accessibility and Equalities Unit, Department for Transport (Yvonne Brown)

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Approvals

Project Manager
C. Inwood

Quality Reviewed
T. Horberry
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Executive summary

Background
The Transport Research Laboratory (TRL Ltd) was commissioned by the Department for Transport’s (DfT) Accessibility and Equalities Unit (AEU) to explore the issues surrounding use of observation devices by people with restricted neck, head or trunk movement. This group of people may find it difficult or painful to make observations during certain driving tasks, such as reversing or negotiating a junction. They may also find it difficult to see into blind spots around the vehicle.

Objectives
The overall objectives of the project were:

- To identify the observation devices currently available for use by people with restricted function;
- To explore and report on the reliability and safety of these devices in compensating for impaired function within the driving task; and
- To make recommendations on the fitting, use, training and licensing requirements of these devices.

Methodology
In order to achieve these project objectives, the research was conducted in five phases:

1. Consultation of key stakeholders to fully understand their concerns regarding the use of observation devices by older and disabled drivers;
2. Review of technologies to identify the observation devices available for use by people with restricted neck/trunk function;
3. User survey to explore the views of people who are already using observation devices or could potentially benefit from them;
4a. In-depth evaluation of seven observation devices, selected with the client following the first three phases, to cover a key range of safety, reliability and usability issues, including:
   i. Expert heuristic/ergonomic evaluation.
   ii. Assessment of range of vision/detection; and
   iii. Inspection of safety of installation.
4b. User testing to assess the ability of the devices to compensate for impairment and to further explore usability issues; and
5. Reporting and recommendations.

1. Consultation
There are a variety of devices on the market that have the potential to assist drivers who have restricted neck or trunk movement with making observations. However, there are a range of usability and reliability issues that may limit the extent to which such devices can compensate for the impairment. These views were expressed by parties such as the Driver and Vehicle Licensing Agency (DVLA), Driving Standards Agency (DSA) and the DfT during the consultation exercise. Chief among the concerns were the ability to judge speed and distance...
based on the view afforded by devices such as cameras and mirrors, distraction caused by looking inside the vehicle at a display, and the distortion of images caused by convex lenses which are designed to give a wider view.

2. Review of technologies

The review of technologies identified six distinct types of device designed to help with observations:

a) Junction cameras, designed to be used at junctions to give a view to the left and right;

b) Reversing cameras, designed to provide a view to the rear of the vehicle for use when reversing;

c) Parking sensors, designed to provide an auditory and/or visual alert to the driver when an object is detected within a certain distance of the vehicle;

d) Mirrors, many different types can be fitted in the vehicle to enhance the driver’s view;

e) Blind spot systems, developed largely in the US to help detect objects in a driver’s blind spot, but still uncommon in the UK. They can incorporate technologies such as radar, digital cameras, and powered side mirrors; and

f) Reversing lens, a small plastic lens that fits to the rear windscreen to provide a wider field of view than normal.

3. User survey

The user survey revealed that the most problematic areas for people with restricted neck and trunk movement were reversing and negotiating junctions. Many of the people surveyed did not use an additional observation device. They described a range of coping strategies which included limiting driving, avoiding reversing, positioning the vehicle to give a better view, taking a “peep and creep” approach at junctions and just “taking a chance”.

Of those that did use an additional observation device, the most popular was the panoramic mirror. Users of this mirror found it useful. Several people expressed an interest in other types of devices such as the auditory parking sensor. Some people currently used this aid and also found it valuable, although did not identify it as essential in order for them to drive. Knowledge and use of more sophisticated devices such as the junction camera was limited.

4. Selection of devices

On the basis of the findings from the first three phases, and subsequent discussions, it was decided to include the following seven devices in the in-depth study:

a) Panoramic mirror

b) Junction cameras

c) Reversing camera

d) Auditory alert reversing sensor

e) Visual alert reversing sensor

f) Blind spot mirrors

g) Gooseneck mirrors

These devices were retro-fitted to the test vehicle used for this study – a Ford Focus Zetec.
5. In-depth evaluation
The in-depth evaluation consisted of three evaluations: the expert heuristic evaluation, the range of vision/detection assessment, and the inspection of safety of installation.

The expert heuristic evaluation was carried out independently by two human factors experts after developing a usability questionnaire to structure their assessment of each device.

The range of vision/detection assessment was carried out on the Central Area of TRL’s test track. A brightly-coloured test object of three different heights, representing the height of a kerb, bollard/child, and car/older child, was systematically moved around a marked out grid to test range of detection. For those devices which were viewpoint dependent (i.e. the panoramic mirror and blind spot mirror), three observers, representing the 5th percentile female, 50th percentile male, and 95th percentile male statures, were recruited to assess range of vision.

The inspection of the safety of installation was carried out by two skilled vehicle safety experts and considered the primary and secondary safety of each device, i.e. whether they had potential to contribute to the cause of a crash and whether they increased the likelihood or severity of an injury in the event of a collision.

6. User testing
The user testing was task-based and conducted on TRL’s small road system of the test track. Ten non-impaired volunteers were recruited in order to objectively assess the ability of each device to compensate for impairment. They were restricted by using an adjustable neck brace in order to simulate impairment in a ‘worse case’ scenario. An additional four volunteers with genuine restricted movement were recruited from the user survey to validate the findings and identify any further usability issues within the driving population who would be using the devices.

Overall findings
The main findings of this research are presented for each device in this report. The junction camera system assessed within this project was designed specifically for drivers who have restricted movement which affects their ability to make observations at junctions. One camera was mounted on each side of the vehicle inside on the A pillars. The image was displayed on a screen integrated with the rear view mirror and controlled by the driver; several interface problems were identified. The junction camera was found to be most beneficial for use at typically ‘difficult’ junctions, such as those with acute angles, and for those participants with more severe restrictions. However, there was no evidence that it could compensate fully for impairment. The system assessed had significant usability issues, which could be improved through better design, and was thought to pose risk to the vehicle occupant in the event of a collision.

A pair of gooseneck mirrors was evaluated; these were small round concave mirrors mounted on short flexible necks and rubber suction pads. It was concluded that they could provide a wide view to aid visibility at junctions but there were problems with fitting, image distortion, and serious constraints within the vehicle which would result in a vast amount of additional irrelevant information being displayed.

The reversing camera system was designed to give an enhanced view directly behind the vehicle and, as with the junction camera system, the image was displayed on a screen integrated with the rear view mirror (with the same interface problems identified). Although the view provided exceeded that of an unrestricted/unimpaired driver, there were no observable objective benefits in performance of the reversing tasks. There were very few usability problems with this device and it was popular with those who had used it.
The reversing sensors installed on the test vehicle consisted of four ultrasonic sensors connected separately to an auditory and visual warning system. The auditory signal was in the form of high-pitched tones which increased in frequency with increasing proximity of a detected object. The visual display consisted of a panel of LED lights which was positioned centrally above the rear window of the test vehicle. Lights lit up according to the location of the detected object (to the left or right) with increasing lights indicating increasing proximity. The detection range for the sensors was only up to two metres from the rear bumper of the vehicle and so could be used to aid low speed reversing manoeuvres by identifying unseen objects close to the vehicle. There was no observable benefit or disbenefit in terms of performance for either system and the potential for over-reliance was identified. More usability problems were identified with the visual display mainly due to the modality conflict, meaning that the driver had to continuously monitor the display rather than divert their attention to other observations.

The panoramic mirror, designed to replace the standard rear view mirror, was larger and had a convex surface which afforded a wider field of view to the rear and sides of the vehicle. Key concerns were the distortion of images, a worse view directly behind the vehicle, and irrelevant information being displayed. It was considered to be more likely to be contacted by a vehicle occupant in a crash. The height of the driver greatly influenced its effectiveness and it was assessed as more useful for general observations around the vehicle rather than specific tasks such as reverse parking or turning in the road. When the panoramic mirror was tested as an aid for viewing the blind spot, it was preferred over the blind spot mirrors for this purpose.

Blind spot mirrors are designed to provide a view of the area around the rear wings of the vehicle, which is particularly important when changing lanes. There are many different types – the design assessed as part of this project was rectangular, with a slightly convex surface, attached to the inside bottom corner of each door mirror, with an adjustable horizontal angle. The assessment showed that the blind spot mirror provided an extra view, (irrespective of the height of the driver), to that of the standard door mirror and extended a long way back but not out to the sides. However, the image was slightly distorted and there seemed to be a misunderstanding by drivers as to the purpose as well as interpretation of the image.

**Recommendations**

Based on the findings of the research, recommendations were made on:

- **Use of devices** - if drivers are to rely totally on any observation aid, then they should only do so if the design of the aid has been given Type Approval and if they have undertaken appropriate familiarisation and/or training.

- **Provision of information to users** - drivers would benefit from clarification regarding where and in which circumstances they should seek advice on driving with restricted movement.

- **Training** - having purchased an observation aid, training or guidance should be provided to ensure that it is used safely.

- **Device design** - the design of all in-vehicle equipment, including driver observation systems, should follow ergonomic good practice.

- **Licensing policy** - the criteria for determining whether people need to rely on a device are not determined, therefore a recommendation for further work to determine an appropriate assessment method and boundary for making judgements is made.
1 Introduction

1.1 Background

The Transport Research Laboratory (TRL Ltd) was commissioned by the Department for Transport’s (DfT) Accessibility and Equalities Unit (AEU) to explore the issues surrounding use of observation devices by people with restricted neck, head or trunk movement.

Safe manoeuvring of a car requires the driver to have a good all round view which includes being able to see the areas behind and to the sides of the vehicle. Vehicle rear view and door mirrors provide a view of some of these areas and can be clearly seen from a normal driving position, but in order to get the best view it is often necessary for a driver to turn their head or body to look behind them or to the sides. Some people suffer from conditions that restrict the extent to which they can turn their head or body or make it very uncomfortable to do so. These people may find it difficult to make proper observations while driving and this has both safety and quality of life implication. There is an increased risk of accidents if drivers cannot make proper observations when manoeuvring and, as a consequence, people will feel compelled to alter their driving behaviour or limit their mileage to reduce the risk.

Observation devices, such as additional mirrors, sensors and cameras, have the potential to compensate for impaired function of the body and/or neck to turn or twist but most have not been independently evaluated. The AEU commissioned work to explore the reliability and safety of a range devices designed to aid people with observations of blind spots, at junctions and when reversing following discussions with DVLA and DSA about drivers using such equipment to compensate for restricted movement.

1.1.1 Evaluation terms

The project aimed to evaluate observation devices from a number of different perspectives. This section outlines what is encompassed under the headings of safety, reliability and usability.

- **Safety** refers to the impact of a device on the risk of accident or injury to the user (driver), vehicle passengers and all other road users. This therefore encompasses the positive or negative effect of the device on the likelihood and severity of an accident and the consequences of having the device present in the vehicle (e.g. users cutting themselves on a sharp edge).

- **Reliability** refers to the ability of the device to work correctly and safely under all circumstances. This therefore includes the likelihood of the device failing; maintenance issues and performance in different weather and lighting conditions.

- **Usability** refers to the properties of the user interface (which includes both controls and displays) in terms of how easy or difficult it is to use. This includes both physical (e.g. the ability to reach to controls) and cognitive issues (i.e. the ability to understand the control functions and device outputs). Usability also considers the design of the interface from the perspective of different users in terms of how their individual abilities or impairments affect the extent to which they can use the device in the intended way.

Clearly there is overlap between these issues. Reliability and usability are both closely related to safety and if a device that drivers rely on to make observations is unreliable or difficult to use the risk of accidents will be increased.
1.1.2  **Current guidance on the use of observation devices**

The following information is quoted from the Car Adaptation Information for Europe Website\(^1\). This website is one of the outputs of the QUAVADIS project. QUAVADIS is a pan-european initiative to improve the Quality and Use Aspects of Vehicle Adaptations for DISabled.

The information on this website refers primarily to the situation where drivers are seated on the left of the vehicle and drive on the right of the road (as in the majority of European countries). In the UK, drivers are usually seated on the right of the vehicle and drive on the left of the road. Therefore, the information provided in this report has been interpreted so that it applies to the UK situation (i.e. left and right have been reversed where appropriate).

The principle requirements for field of vision for driving a car are divided into direct (i.e. field of vision seen directly with the drivers eyes) and indirect (i.e. field of vision covered by the compulsory rear view mirrors). The following sections describe the requirements for direct and indirect vision as described in QUAVADIS Code of Practice.

### 1.1.2.1  Direct vision

- **Field of vision in forwards direction** - Drivers forward field of vision must include the full view through the windscreen complemented with the view through the side windows on the left and right.

- **Field of vision to the left** - The driver must be capable of looking through the side window(s) on the left side of the vehicle. Torso rotation is allowed as long as the steering and handling of the vehicle is not negatively influenced and the normal driving position with two hands on the steering wheel can be maintained.

- **Field of vision to the right** - The driver must be capable of turning his/her head at least 45° to check the blind spot on the right of the vehicle. Torso rotation is allowed as long as the steering and handling of the vehicle is not negatively influenced and the normal driving position with two hands on the steering wheel can be maintained.

### 1.1.2.2  Indirect vision

Interior rear-view mirror  Figure 1 shows the field of vision required to be provided by the interior rear-view mirror. This requirement is set out in item 5.2 of Annex III of 71/127/EC.

![Figure 1 Required field of view provided by interior rear view mirror](image)

- Exterior rear-view mirror on driver’s (right in the UK) side - The exterior rear-view mirror on the driver's (right) side of the vehicle is compulsory for every vehicle of category M and N. This mirror should provide the field of vision depicted in Figure 2.

• Exterior rear-view mirror on the left side - An exterior rear-view mirror on the left-hand side of the vehicle is not compulsory for M1 and N1 vehicles unless needed because of the design and/or loading of the vehicle. If fitted, such a mirror shall satisfy the requirements shown in Figure 2 (defined in clause 5.3.2 of Annex III of 71/127/EC).

![Main exterior rear-view mirror for vehicle driven on the left.](image)

**Figure 2 main exterior rear-view mirror for vehicle driven on the left\(^2\) of the road for vehicles in category M and N not exceeding 2 tonnes in weight.**

### 1.1.2.3 Regulations for drivers with restricted neck or trunk movement

Drivers who are restricted in the movement of the neck or spine due to either functional impairment or orthopaedic devices (e.g. a brace or collar) and therefore cannot fulfil these recommendations for direct or indirect field of view shall compensate by means of additional or modified rear-view mirrors.

The term modified rear view mirrors refers to where rear-view mirrors have been adapted in terms of number, location, size, shape or nature, in order to obtain the required field of vision.

If drivers rely on such devices their use should be reported to the DVLA so that the appropriate information code can be added to their driving licence. The code for modified rear view mirror(s) is 42 and there are various additional sub-codes which refer to the specific type of modification required.

**For UK drivers with restricted movement to the left:**

- If movement to the left is restricted such that drivers can only look through the windscreen and first left side window (driver can look up to about 90° to the left) then a left-hand exterior rear view mirror is compulsory (Code 42.01)
- If the driver’s movement is more severely restricted such that the driver can hardly move the head (driver can look up to about 45° to the left) then the missing field of vision can be compensated for by:
  - fitting a panoramic interior rear-view mirror (42.04)
  - position the left-hand exterior rear-view mirror forwards to the wing (42.02)
  - fitting an additional interior mirror to permit view of the traffic that comes from the left (42.03)

\(^2\) This figure is an adapted version of the requirement diagram from section 5.3.1 of Annex III of the 71/127/EC. The original diagram has been inverted to illustrate the UK requirement for vehicles with the driver seated on the right and driven on the left of the road.
For UK drivers with restricted movement to the right:

- If movement to the right is restricted such that a driver can only look through the windscreen and first right side window (driver can look up to about 90° to the right) then a blind spot mirror is compulsory (Code 42.05)
- If the movement to the right is more severely restricted (such that the driver can look up to about 45° sideways) then the driver can compensate by using an additional interior mirror to permit the view of traffic coming from the right (Code 42.03)

**Note on the definition of mirrors**
Currently modified rear-view mirrors are the only type of additional observation devices covered under the EC directive on driving licence codes. The term rear-view mirror refers to “Any device, excluding complex optical systems such as periscopes, intended to give a clear view to the rear and side of the vehicle.”

### 1.2 Project objectives and overview

The project was conducted in five phases, an overview of which is shown in Figure 3.

**Figure 3 Project overview**

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3 Definition from 71/127/EC, Annex I
The specific objectives of this project were:

- To identify the observation devices available for use by people with restricted function;
- To explore and report on the reliability and safety of these devices in compensating for impaired function within the driving task; and
- To make recommendations on the fitting, use, training and licensing requirements of these devices.

1.3 Report structure

This report details the findings of each of the phases, and is structured in the following manner:

Section 2 – Consultation: Results of the consultation process which explored the concerns of legislative and other bodies about the use of the equipment, legislative considerations surrounding its use and their view on what should be included in this project.

Section 3 – Review: A technical review of the technology available that has a potential benefit for people with restricted head and trunk movement. This included an initial desktop consideration of the usability and reliability concerns with each type of equipment.

Section 4 – User survey: The results of a user survey which explored the views of people who suffer from restricted movement regarding areas of difficulty, current coping strategies and the use or potential use of observation devices.

Section 5 – Devices evaluated: This outlines the decision-making process in which the devices to evaluate in-depth were selected. It also details the vehicle used and method of artificially restricting participants.

Section 6 – Expert heuristic evaluation: This section details the methodology and results of the ergonomic evaluation by human factors experts.

Section 7 – Range of vision assessment: This section details the methodology and results of the assessment of range of vision/detection.

Section 8 – Inspection of the safety of installation: This section details the methodology and results of the inspection of safety of installation by vehicle safety experts.

Section 9 – User testing: This section consists of a description of the testing of each of the devices using objective and subjective measures to evaluate their ability to compensate for impairment and further usability issues.

Section 10 – Discussion and conclusions: This section will bring together the findings of each of the phases of the project.

Section 11 – Recommendations: Based on the findings from this project, recommendations are made on the fitting, use, training and licensing requirements for these devices.
2 Phase 1: Consultation

2.1 Aim
The aim of the consultation was to fully understand stakeholders’ concerns regarding the use of observation devices by older or disabled people with restricted neck and trunk movement.

2.2 Method
Telephone conversations were conducted with representatives from the following organisations:

- DVLA (medical branch);
- DSA (policy and examination);
- Motability;
- DfT’s Transport Technology and Standards Division (TTS);
- Two companies who fit adaptations; and
- Three mobility centres.

They were asked about which devices they were aware of, their concerns over the use of observation devices and whether there were any specific issues for particular devices, what information would be required, existing legislation/standards and responsibilities, barriers or limitations to using equipment and whether they thought observation devices compensate for the impaired function.

2.3 Findings

2.3.1 Devices mentioned
Devices mentioned during the consultation included the following:

- Junction cameras (see section 3.3.1) fitted to the outside of a vehicle or windscreen and driver-activated to look left/right at junctions rather than during the general driving task
- Reversing or parking sensors (see section 3.3.3) which can be retro-fitted or Original Equipment Manufacture (OEM)
  - Warning systems (auditory) sonic or infra-red
  - Radar units linked to rear-view mirror with speed/distance indicators
- Panoramic rear view mirror (see section 3.3.4.3) which are fitted onto the existing rear view mirror to give additional visibility
- Blind spot mirrors (see section 3.3.4.1) which can adhere to the vehicle’s interior or can clip to the top of the wing-mirrors
- Gooseneck mirrors (see section 3.3.4.2) which are fitted to the inside of the windscreen with a flexible neck to adjust
- Reversing lenses (see section 3.3.5.2) which stick to the back windscreen.
2.3.2 Concerns about devices

Table 1 shows concerns about the use of observation devices.

Table 1 Concerns about the use of observation devices

<table>
<thead>
<tr>
<th>General area</th>
<th>Specific concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitability of devices for individuals</td>
<td>Consideration of driver sensory capabilities, e.g. ensure hearing abilities if using audible signals</td>
</tr>
<tr>
<td></td>
<td>Need for a ‘back up’ system if vital to compensate for impairment</td>
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<tr>
<td></td>
<td>Whether actually compensate at junctions, especially those more than 90 degrees</td>
</tr>
<tr>
<td>Installation and maintenance</td>
<td>Expensive fitting costs for some devices</td>
</tr>
<tr>
<td></td>
<td>Confidence in professional fitting and maintenance to ensure the device will not ‘break down’</td>
</tr>
<tr>
<td>Training/advice important</td>
<td>Accuracy of speed and distance judgements with use of video cameras (especially if 100% reliant on)</td>
</tr>
<tr>
<td></td>
<td>Delay in accessing information from camera and mirror</td>
</tr>
<tr>
<td></td>
<td>Optical illusions or distorted image when using mirrors</td>
</tr>
<tr>
<td></td>
<td>Clarity of image affected if dirty or in glare</td>
</tr>
<tr>
<td></td>
<td>Size/resolution of image from camera and whether in colour</td>
</tr>
<tr>
<td></td>
<td>Whether cameras work in poor weather/at night</td>
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<tr>
<td></td>
<td>Over-sensitivity of reversing sensors</td>
</tr>
<tr>
<td>Negative safety implications</td>
<td>Mirrors creating blind spots/obstructing view</td>
</tr>
<tr>
<td></td>
<td>Mirrors impeding air bags</td>
</tr>
<tr>
<td></td>
<td>Over-confidence (reduce safety checks)</td>
</tr>
<tr>
<td>Distraction caused</td>
<td>Particularly for high tech end of market</td>
</tr>
<tr>
<td></td>
<td>Trust issue with mirrors as spend more time looking at them rather than road – impact may lessen over time</td>
</tr>
<tr>
<td></td>
<td>Less concern for reversing sensors as activated when needed</td>
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</tbody>
</table>

2.3.3 Legislation, standards and responsibilities

Views on legislations, standards and responsibilities were generally that they are confusing and insufficient. The comments concerned the following:

- Identification of need for a device
  - Individual to seek advice if concerns over observations
  - Motability and mobility centres (and possibly suppliers) advise about what is suitable and available
    - Decisions over fitness to drive with DVLA/DSA
- Use of device
 Motability/mobility centres thought advice about use ultimately lies with supplier/retailer

- DSA responsible for setting acceptable standards
- If devices are used when an individual is taking a practical driving examination it’s use should be noted on their license as they are not demonstrating competence without the device (a parallel was drawn to if someone is unable to use a manual transmission vehicle they should have a code on their licence that they are only permitted to drive an automatic)
- “If a device is vital to enable someone to drive, it should be coded on their licence so transparent/enforceable.”
- Important to ensure someone does not have significant visual defects if they are going to rely on devices

2.4 Conclusions in relation to the research

The consultation showed that stakeholders considered it desirable for the research study to encompass several factors.

Issues to consider within the research consisted of the following:

- Safety of devices and whether they compensate for impairment; including objective measurements. This was examined in phases 4a and 4b.
- Coping mechanisms used by drivers to adapt/compensate (this was included in phase 3 user survey); and
- Differences with whether devices are essential or assistive (subjective information on this was also included in the user survey).

Aspects which should be considered in light of the findings, which were generally outside of the scope of this project:

- Advice should be issued to users at assessment stage to ensure appropriate choice of devices;
- DSA and mobility centres to work together to ensure safety whilst not restricting a person’s mobility unnecessarily.
- Guidelines issued on training and ways to increase awareness of the issues (e.g. publicity on the DVLA website).

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4 Vision impairments was not within the scope of this project.
5 This is a guarantee that the product complies with EC regulations on, for example, dimension and performance (tested via physical and impact tests).
6 Bioptics are eye glasses or lenses which have a small telescope to increase visual acuity but can affect field of vision. It was not within the scope of this research project to explore this.
3 Phase 2: Targeted review of technologies

3.1 Aim
The aim of this phase of the research was to identify the observation devices currently available for use by people with restricted neck and trunk movement.

3.2 Method
A wide range of sources were used to conduct the search for observation technologies. This included sources provided by the forum of mobility centres, manufacturer's websites, adverts in disability magazines and databases of academic journal abstracts.

3.2.1 Manufacturer search
Internet search engines (Google and Google Scholar) were used to identify websites of manufacturers of observation devices and adaptation specialists who might provide such devices. The searches used all combinations of the key words listed in Table 2. For a list of the manufacturers identified and their websites, see Appendix A.

3.2.2 Academic sources
Two major academic databases were used to search for literature relating to observation technologies for older and disabled drivers. These were Science Direct and SpringerLink. Both databases were searched using all combinations of the key words listed in Table 2. Search combinations were constructed so that one word from each column was used in each different combination.

<table>
<thead>
<tr>
<th>Table 2 Key words used to search for relevant technologies</th>
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<tbody>
<tr>
<td>Disability</td>
</tr>
<tr>
<td>Elderly</td>
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<tr>
<td>Restricted movement</td>
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Searches on both databases utilised the site’s search operators to look for words with the same prefix. For example, on the SpringerLink site the search term “Adapt*” was used to search for “adapt”, “adapted” and “adaptation.”

In order to produce the most relevant search results the search criteria were narrowed so that only articles and papers published between 1st January 2000 and day of the search were returned. Both databases incorporate a huge range of source material so it was also necessary to narrow down the sources to be searched. In Science Direct the subject areas “nursing and health professions”, “psychology” and “social sciences” were selected. In SpringerLink there was the facility to select relevant journal titles.

The following were selected to be included in the search:

- AGE
3.2.3 Other sources

3.2.3.1 University departments

A search was undertaken for University departments engaged in disability research. This yielded the Disability Archive UK which is administered by the University of Leeds Centre for Disability Studies and provides online access to papers and book chapters relating to disability.

- University of Leeds Centre for Disability Studies
- University of Glasgow Strathclyde Centre for Disability Research
- Cardiff University UnumProvident Centre for Psychosocial and Disability Research

3.2.3.2 Mobility Road Show

A team of researchers visited the Mobility Road Show and used this opportunity to see installed examples of some of the devices.

3.3 Types of device

The following section presents an overview of the types of devices that are available, and the different options available within each category. Devices were grouped into six categories according to their main functions and features. The categories are:

1. Junction cameras
2. Reversing cameras
3. Reversing and parking sensors
4. Mirrors
5. Blind spot systems
6. Reversing lens

For each type of product, this section of the report describes its purpose, features, installation requirements, approximate cost and different control and display options. This phase of the project identified some potential reliability and usability issues for each product.
3.3.1 Junction cameras

3.3.1.1 General description

Junction cameras are primarily designed for people who have difficulty turning their head in order to view traffic in a junction situation. The cameras are mounted on both sides of the vehicle near the front and provide a view to the front and sides of the vehicle. Figure 4 provides a representation of the view that can be provided by junction cameras.7

![Figure 4 Representation of the view provided by junction cameras](image)

Systems of this nature can potentially allow easier detection of vehicles which are approaching from the side, for example, at a T-junction. The camera view is displayed on a small screen within the vehicle and there are several different options about what display the screen can show.

3.3.1.2 Installation

The system consists of cameras, a display screen and a control panel. At the time of this project no system was available on the UK market as a complete product containing all the elements. Rather, specialist installers have sourced the different parts and created bespoke systems. This type of system must be retrofitted; it is not currently available as a standard option in new vehicles and would need to be installed by a professional. Each camera needs to be specially fixed to the vehicle. Power needs to be supplied to the cameras and screen and suitable wiring is needed to connect the different elements of the system.

Depending on where the cameras are mounted, installation may require modifications to the body work of the vehicle. It seems that cameras are usually mounted inside the vehicle near to door mirrors (see Figure 5 and 6). It is also possible to have externally mounted cameras, although it is probable that security and injury risks to other road users make this option less attractive.

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7 Note: This diagram is a representation for illustrative purposes only. It is not intended as an accurate quantification of the view provided by junction camera systems.
Figure 5 Junction camera fitted to the A pillar.

Figure 6 Junction camera system

Figure 5 and 6 show examples of two different cameras that have been used in a junction view system. Any small camera could be used with the system and the quality of the picture, field of view and cost would all vary accordingly.

Different types of lenses could be fitted to the cameras which would result in different image characteristics. For example, a wide angle or fisheye lens will result in a wider field of view but may result in distortion of the image. A telephoto lens could be used to produce a clearer image of objects that are further away but may make it difficult to judge the distance between the viewer and the object as distant objects would appear closer than they are in reality. Given the limitations of both types of specialist lens a typical system would probably employ a standard type camera lens to minimise distortion, although the user could chose a different
type depending on their specific needs. Colour and black and white cameras are both available and could be used in a junction camera system. Colour would be preferable in most cases but is more expensive than monochrome.

3.3.1.3 Feedback and control method

In junction camera systems, the image is usually displayed on a small LCD screen in the vehicle. Any small LCD screen could be used to display the view providing it can be powered and installed securely in the vehicle. As in the case of the cameras, the quality of the image, cost and effectiveness of the system will be affected by the choice of monitor. The system displayed in Figure 6 uses a dashboard mounted monitor. In theory, the monitor could be mounted in any position on the dashboard. However, the position of the screen in relation to the driver and other systems within the vehicle will influence usability and user comfort.

As an alternative to a dashboard mounted screen, an embedded screen is available that displays a small image in the rear view mirror (see Figure 7). The image can be activated by the driver when required and the rest of the time the rear view mirror operates as a normal mirror, although the examples presented at the Mobility Road Show had a darker tint in the glass than a standard mirror. As shown in Figure 7, this type of screen is mounted over the vehicle’s existing rear view mirrors and wiring is run though the roof lining of the car.

Control of a junction camera system can be set up in various ways. For example, it can be linked to the vehicle secondary controls. In the system shown in Figure 6 it was set up such that when the right indicator was activated the view to the left was displayed and when the left indicator was activated the view to the right was displayed. This configuration only allows the user to see in one direction. In many junction situations, particularly when turning right, it is crucial to have a good view in both directions. According to the nature of the driver’s movement restriction they may prefer to use the camera in one particular direction and this configuration does not allow the user to choose the view that best suits them. Despite
the limitations, in some cases linking the camera view to other controls may be the best option as it limits the number of controls that need to be used. Although it might be argued that the usability would be adversely affected when one control device is used for several unrelated functions.

The view displayed could be controlled using an electronic button pad which may also have other functions in addition to control of the junction camera view.

Both of the examples displayed at the Mobility Road Show showed only one image at a time (i.e. left or right, not both simultaneously). With the correct video multiplexing equipment it would be possible to set up a system that displays two or more views at the same time. However, splitting a screen to display multiple images is likely to reduce the size of all images and potentially cause distortion if it requires the images to be stretched or compressed.

### 3.3.1.4 Indicative cost range

The cost of installing a camera system such as that shown in Figure 7 would be approximately £650 with a single camera and an additional £250 for each additional camera. Systems including a screen and a single camera which could be suitable as a junction camera are available on the internet for between £300 and £600 and suitable cameras could be purchased for between £60 and £200 each.

### 3.3.1.5 Potential reliability and usability problems

In both of the system examples observed, the positions and angles of the cameras were fixed. Whilst this option might be the simplest to operate, there was a concern that this might be suboptimal for junctions with acute angles, especially on narrow roads where it is not possible to angle the vehicle to improve the camera views (e.g. Figure 8). The same concern applies if there are obstructions at junctions which occlude the camera’s view (e.g. trees, street light posts etc.). Drivers tend to compensate by moving their head, turning, twisting or leaning to see round an obstruction. This is not possible for drivers with restricted neck or trunk movement and quite a small obstruction could create a blind spot big enough to hide a pedestrian, cyclist or even a car.

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8 Source: PB conversions
It is possible for the cameras in a junction view system to be mounted externally. If this was the case there is a possibility that the driver’s view could be impaired if the cameras became dirty. This concern also applies to reversing cameras which are discussed in the next section.

It is unclear whether a junction camera system would provide an adequate view in all ambient light conditions. In bright sunlight the screen may be washed out so the image is difficult to see and at night reflections from street lighting and lights within the vehicle may produce reflections which make the image hard to see. Screen settings that are suitable for daylight conditions are not always suitable for dark conditions. For example, a very bright screen designed to be viewable in bright light can dazzle the driver at night and reduce their ability to see ahead. Although this could, in theory, be possible to control by the driver (e.g. by brightness controls), it would make the system more complex and probably more difficult to use.

Finally, there is a risk that cameras could be mounted in a position that would occlude the driver’s normal forward view from the vehicle, the view of the door mirrors or they could obstruct other equipment such as airbags.

### 3.3.2 Reversing cameras

#### 3.3.2.1 General description

Reversing camera systems are designed to display an image of the area behind the vehicle to the driver via a screen mounted somewhere within the vehicle. Unlike the junction camera systems, reversing camera systems are not specifically designed for people with restricted neck and trunk movement. However, they could potentially be useful for people who find it hard to turn in their seat to look out of the rear screen and find the normal mirrors insufficient for reversing manoeuvres. A typical camera system might include a monitor with mounting bracket, a camera with mounting bracket, a control module (with camera input and VCR output), and a cable to connect the camera to the control module (e.g. the ‘colour flat screen system’ by Marcle Leisure).
3.3.2.2 **Installation**

Reversing cameras are available as an option with some new vehicles or the systems can be retrofitted. Complete kits which include a camera, screen and all the required cabling are easily available on the internet and in shops. Some systems also incorporate parking sensors, which are discussed in the following section of this report. Most systems use a single camera which is mounted to the rear of the vehicle, usually in the bumper or area around the number plate. Installation is likely to require a small hole to be cut in the bumper or bodywork of the vehicle (see Figure 9). It is therefore likely to require professional installation, although some people may have the skills to install the system themselves.

![Figure 9 Examples of reversing camera installation](image)

The installation would certainly require mounting of the camera and connection to a power source. It is common practice for reversing camera systems to be automatically activated when the vehicle is put into reverse gear so this would also be required. This is achieved using a feed from the reversing light. Mounting of the screen and other wiring connections may also be required. Some systems have a screen which is designed to be removed when the vehicle is not in use; this may not require professional installation. Also, some systems are advertised as “wireless” which implies that cables would not need to be run between the different components of the system.

3.3.2.3 **Detection methods**

Detection of objects is via the camera image displayed on a screen in the vehicle. As with junction view systems, different camera options are available. Reversing cameras are more widely available as whole systems, so the choice of camera may realistically be limited to the ones provided with a particular system. Reversing cameras tend to be supplied with a wide angle lens because they are designed to give the best possible view of the area to the rear of the vehicle quite close to the camera lens enabling the driver to detect any obstructions behind the vehicle.

Night vision cameras are available with some systems. These systems detect when the light levels are low and automatically switch to night vision mode to display a clearer image in black and white.

3.3.2.4 **Feedback method**

As with junction camera systems, the screen to display the video image can be mounted on the dashboard or within the rear view mirror and all of the same options are available in terms of colour versus black and white, mounting position etc. In vehicles where the system is
supplied as an option when buying the car, the view may be displayed on the main dashboard screen and the screen may be shared with other vehicle systems such as the radio or satellite navigation.

![Example of reversing camera system available as an option in a new vehicle](image)

**Figure 10** Example of reversing camera system available as an option in a new vehicle

The exact view provided by the camera is dependent on its position on the rear of the vehicle. In the example shown in Figure 10, where the camera is mounted above the number plate and angled downwards, it is possible to see the rear bumper of the vehicle. This may be a useful cue to judge the distance between the vehicle and any obstruction. Other systems provide no view of a reference point on the vehicle (e.g. in bumper mounted cameras). There is a slight concern if the camera is mounted off-centre that the driver would not have an adequate view on the far side from the camera.

The system shown in Figure 10 also has a colour coded distance scale imposed on the image to help the driver judge how far away objects are. This may be another useful cue. Some reversing camera systems come integrated with reversing sensors. In these systems the display from the camera may be supplemented by auditory or visual signals produced by the sensors which will be discussed in depth in the next section.

### 3.3.2.5 Indicative cost range

The cost of a reversing camera system varies dramatically according to the quality of the camera and display equipment. Reversing cameras with additional sensors and a removable clamshell display are available for between £150 and £200. Dedicated reversing cameras with higher specification cameras range between £300 and £600 depending on the choice of camera and screen. Similar systems with a screen in the rear view mirror range between £450 and £600. All of these cost ranges do not include the cost of fitting. Factory fitted systems cost between £500 and £700, but at the time of this review they are only available from a limited number of manufacturers (prices based on Mercedes and Nissan vehicles).
3.3.2.6 Potential reliability and usability issues
Several of the concerns raised regarding junction cameras also apply to reversing cameras. Reversing cameras are much more likely than junction cameras to be mounted externally. They are also lower to the ground which means that they are more likely to become dirty with a resulting reduction in visibility. The same issue of the display screen becoming washed out in bright sunlight also applies. However, reversing cameras are a much more developed product than junction cameras so the design of some products may have already taken this into account.

The camera may provide an incomplete view of the area behind the vehicle, particularly if it is positioned off-centre. There is a risk that people may come to rely on the system without fully understanding the limitations of the view provided. The system depicted in Figure 10 bears the safety message “check behind before reversing” which suggests that the manufacturer does not want to be liable for the reliability of the system in terms of displaying all possible obstacles. This may be a symptom of the fear of litigation rather than an indication of system limitations; however, the system was clearly designed as an additional extra comfort system for drivers who are physically able to turn around and look behind, rather than a device to allow drivers to reverse, who without it cannot safely complete such manoeuvres.

Finally, it may be quite difficult to control the car according to the feedback provided by the reversing camera. The movement of the image may be difficult to interpret and react to and it is possible that effective use would require a substantial amount of practice.

3.3.3 Parking sensors
3.3.3.1 General description
Parking sensors are another form of technology that are not designed specifically for drivers with movement difficulties but may provide some compensation. They are designed for anybody to use during parking manoeuvres by detecting obstacles around the vehicle and warning the driver when they are within a particular distance. The sensors can be fitted to the front or rear of the vehicle and are set-up to provide an auditory or visual warning when an object is detected.

3.3.3.2 Installation
Parking sensors are now widely available in new vehicles and as after market systems. When bought as an aftermarket system, parking sensor kits are comprised of the sensors, a central processing unit, wiring and a feedback device. Several systems advertise themselves as self-fit and claim that the system can be installed quickly by anybody with basic DIY skills and tools. However, a professional could also be employed to fit any type of reversing sensor system.

The easiest type of system to install has self adhesive sensors that stick onto the vehicle bumper or number plate. ‘Recessed’ sensors are also available which are designed to lie flush with the vehicle body work (e.g. Figure 11). Recessed sensors can be colour coded to match the paint work of the car and require holes to be made in the bodywork, usually the bumper (e.g. Figure 12).
Sensors are most often installed at the rear of the vehicle but they can be installed anywhere where there is a risk of striking an object, including the front and sides of the vehicle. Figure 11 and Figure 12 show the most common type of sensors which are ultrasonic. There are several other types of sensors and these are discussed in the following section.

Reversing sensor systems are usually activated automatically when the car is put into reverse gear. This is achieved using a feed from the reversing light. Sensors on the front of the vehicle are sometimes activated when the brake is used and this would be achieved in a similar way. Some systems claim to accept voice commands as well although it is unclear what functions this would control.
3.3.3.3 Detection methods

Parking sensors are available that use a variety of different detection methods. The majority of the sensors work on an active sensing principle in that they emit a form of energy then detect the reflection of that energy when it comes back to the sensor.

The most common type is ultrasonic and these sensors look just like those described in section 3.3.3.2. Ultrasonic sensors work by emitting a signal which bounces back off any objects that are within the signal range. The sensor receives the returned signal which increases in frequency the closer the object is to the sensor; this allows the system to work out the proximity of the object. For best performance ultrasonic sensors need to be mounted parallel to the road surface. Radar and microwave sensors work in a similar way but emit different types of energy. The object density and water content of an object affects the distance at which microwave sensors will be able to detect it.

One alternative is to use an electromagnetic sensor. These take the form of an antenna strip that generates an electromagnetic field. The sensor can detect changes in the field in terms of masses invading it. This system has the advantage over ultrasonic sensors in that it is not disrupted by items attached to the rear of the vehicle, such as a tow bar or spare tyre and the antenna strip can be mounted on the inside of the bumper so it is not visible on the exterior of the car. An electromagnetic sensor does not work with a metal bumper and it can only detect changes in the field once the vehicle has started moving.

Laser sensors operate on a ‘time of flight’ principle by sending a narrow laser pulse beam towards an object and measuring the time it takes to be reflected off the object and return to the source. Laser parking sensors are much more expensive than other types of sensors and less widely available. Sometimes, only one sensor will be fitted to the front or rear of the vehicle. As the beam is narrow and there is usually only a single sensor, this type of system is more suited for situations where a large obstacle is directly in front of or behind the vehicle, for example, to help drivers get close to the back wall of a garage without hitting it. Laser parking sensors may interfere with other laser devices.

3.3.3.4 Feedback method

There are many different options for the presentation of the warning feedback and they may be used alone or in combination with each other. The most common warning is an audible tone or buzz which rises in pitch and/or frequency as the vehicle moves closer to the detected object. Some systems use a “zone” concept that presents different tones for objects at different distances from the vehicle. The zones would be described in the vehicle’s user manual. For example, an object within the zone 25-50cm from the vehicle may be signalled with a rapid beep and an object within 25 cm of the vehicle may be signalled with a continuous tone. This has the advantage that the driver can interpret the feedback in terms of a real distance. As an example, the Speedsafe LCD display Ultrasonic Parking Sensor has a central control unit which operates a warning comprised of a digital LCD display with an inbuilt audible alarm.

Audible tones would obviously not be suitable for people with hearing difficulties. The tones tend to be high pitched and are therefore quite likely to be difficult for many older people to hear. Some systems are advertised as having a ‘deep’ tone and this may be more suitable for older users.
Simple visual feedback can be provided via a light (e.g. a flashing LED) placed somewhere within the driver’s view. The frequency of the flashing increases as the proximity of the obstacle increases. Some systems employ more complicated visual feedback using a panel of coloured LEDs which can indicate the position of the obstruction as well as an indication of its proximity. In some systems this colour coded system is displayed in a rear view mirror which would be clipped over or replace the existing mirror (e.g. Figure 13).

![Figure 13 Example of a colour coded display integrated with the rear view mirror](image)

In other systems the display is attached to the rear of the vehicle and the driver is required to look in the rear view mirror to see the display (see Figure 14).

![Figure 14 Example of colour coded display fitted to the rear of the vehicle and seen through the rear view mirror](image)
Some systems are provided with a digital display which provides information relating to the proximity of the obstruction. This would usually be presented in terms of a distance. Some systems have the ability to indicate which sensors are detecting the object to allow the driver to assess which side of the vehicle the object is closest to. Parking sensors are also sometimes sold as a package with a reversing camera system.

3.3.3.5 Indicative cost range

The cost of a parking sensor system is highly varied because there are so many different sensor and display options. A basic system with two ultrasonic sensors an audible alert is likely to cost around £50 and a more sophisticated system with eight sensors and a positional and distance LCD visual indicator would be available for around £150.

3.3.3.6 Potential usability and reliability concerns

In systems where a simple audible or visual alert is given it may be difficult for users to interpret what this means in terms of how far the detected object is from the vehicle. This may lead users to react to the stimulus as though they will hit the obstacle if they continue, which will reduce the utility of the device. It is also difficult for drivers to determine what type of obstacle is being signalled by the sensors. For example, if reversing into a parking space, the user might interpret the alarm to be warning them about another vehicle that they can see and are aiming to reverse close to, they may not realise that the warning actually relates to a post behind the vehicle and this misinterpretation may cause them to collide with the post.

With parking sensors, there is also a risk of false or nuisance alarms where the alert is triggered by insignificant objects (e.g. a low kerb) or when there are no obstructions of any kind. The frequency of false alarms will vary according to the type of sensor and the way that it is aligned. Unfortunately, there is no easily comparable information available on the accuracy of different types of sensors. False and nuisance alarms can lead to user frustration with a system and eventually a loss of confidence which might limit the value of the system to the user.

Similarly, different types of sensors have strengths and weaknesses in identifying different types of objects and reliability is affected by different factors (e.g. objects attached to the rear of the vehicle). There is a risk that some objects may not be reliably detected and this would be an important issue to investigate.

It may also be difficult for users to find out what the detection range of their system is in terms of both width (area across the back of the vehicle) and length (distance from the rear or front bumper of the vehicle). Many different options are available and the number of sensors provided with standard kits ranges from one to eight. It would be very important for effective use for people to fully understand the capabilities and limitations of the system they have.

One concern with systems that provide visual information is that there will be a ‘modality conflict’ when using the equipment. While it is relatively easy to look at something (e.g. the rear view mirror) and listen to something (e.g. a parking sensor warning tone) at the same time; it is difficult to look at two different things at once, especially if they are spatially separated. Systems where the visual display is integrated with the rear view mirror would avoid this problem to a certain extent, although there are other places that the driver would need to look during a parking manoeuvre.
There are many different types of parking sensor available. If people with restricted neck or trunk movement were considering relying on such a system it would be essential for them to be able to make an informed choice about what system is best for them. The current situation is that different systems are on sale from many different sources and the information given is not always comprehensive. There is currently no easy way for the consumer to make a comparison between different systems.

3.3.4 Mirrors

The literature revealed that there are many mirrors designed to purportedly help older or disabled drivers with restricted neck and trunk movement. DVLA legislation states that if additional mirrors are required to drive safely due to medical conditions, the DVLA’s medical group should be contacted in order for an information code to be recorded on the driving licence (the licence code for modified rear view mirrors is code 42).

3.3.4.1 Blind Spot Mirror

Blind spot mirrors generally come in two main shapes; circular or rectangular (see Figure 15 for examples) and typically adhere to the door mirrors. The function of the blind spot mirror is to enable drivers to see into the area on each side of their vehicle which cannot usually be seen. This is achieved by the use of convex lenses in the mirrors which create a greater field of vision, allowing the driver to see more of their surroundings without having to twist or turn. The extent of these blind spots depend on many vehicle characteristics together with the height of the driver and the height of the object to be detected. Blind spot mirrors are useful for people with restricted neck and trunk movement as they can assist in manoeuvres such as changing lane and reversing.

![Figure 15 Circular and Rectangular Blind Spot Mirrors](image)

Some newer cars do come with extra blind spot sections incorporated into the exterior door mirrors; they are identifiable by a dotted line on the far side of the mirror (see Figure 16). These additional sections are more convex than the regular door mirrors and therefore allow the driver to see further into their blind spot than regular door mirrors.
A potential reliability issue surrounding the use of blind spot mirrors is that the convex curvature of the mirror could create a distorted image; it has been suggested that convex lenses make objects appear to be smaller and further away, thus giving the driver the impression that they have more time to perform a manoeuvre than they actually do. Potentially, distorted images produced by the mirror could have safety implications if drivers rely on them totally to perform manoeuvres such as reversing, lane changing or overtaking. Another potential problem with using blind spot mirrors is that while they may help people with restricted neck and trunk movement to change lanes and reverse, they would provide minimal assistance to people attempting to negotiate sharp junctions. Australian research also found that blind spot mirrors might be useful for close parking manoeuvres, but that they were not effective for detecting children while reversing (Paine & Henderson, 2001) which gives rise to another safety-related issue.

3.3.4.2 Gooseneck mirrors

Gooseneck mirrors are mounted on a flexible ‘neck’ which allows them to be bent and moved to an appropriate position to allow maximum visibility (see Figure 17). Gooseneck mirrors are generally mounted inside the car; they are often fitted to the dashboard area or to the side windows or windscreens (underneath the existing rear view mirror). The flexible neck allows the driver to position the mirror to assist with reversing, lane-changing and three-point turns. Similarly to blind spot mirrors, gooseneck mirrors typically have convex lenses; therefore, potential problems could arise relating to the distorted images which may be produced by the mirrors. Furthermore, the mirrors themselves could potentially create blind spots by being adhered to the dashboard or windows.
3.3.4.3 **Panoramic mirrors**

Panoramic mirrors are elongated rear view mirrors which can increase rear-view visibility (see Figure 18). Panoramic mirrors typically fit on to or in place of existing rear view mirrors. The convex curvature of the mirror provides the driver with an increased view of the road behind and to the sides of the vehicle, allowing people with restricted neck and trunk movement to see more behind and to the sides without twisting and turning in their seat. Like the other mirrors discussed above, while the panoramic mirror might be useful for overtaking, lane changing and reversing, it provides little assistance for drivers with restricted neck and trunk movement when it comes to pulling out of junctions.

![Image of Panoramic Mirror](image18.jpg)

**Figure 18 Panoramic mirror**

3.3.4.4 **Lane changing mirrors**

Lane changing mirrors are designed to aid drivers with chronic back and neck problems. They work by attaching to the top of the existing rear view mirror with adhesive tabs and as such allow the driver to see the view provided by the normal rear view mirror. This is in addition to being able to check blind spots in the additional mirror (see Figure 19). Their convex lens provides drivers with a wider field of visibility on both sides of the vehicle (see Figure 20). The main function of the lane-changing mirrors is to improve the drivers view when changing lanes; they also increase visibility when performing reversing manoeuvres.

![Image of Lane Changing Mirrors](image19.jpg)

**Figure 19 Representation of the enhanced view produced by lane changing mirrors**
3.3.4.5 Installation

Most additional mirrors come with instructions to enable drivers to fit them themselves. The findings of the literature review suggest that fitting of additional mirrors is relatively straightforward as most come with adhesive strips to stick them to car interiors or door mirrors; others (mainly panoramic mirrors) are supplied with brackets to fix them to the existing rear view mirrors. Cars do not generally come with additional mirrors, so retrofitting of the devices is required. Mirrors typically range from £1.99-£18.00, and can be obtained from a variety of sources such as:

- Suppliers of car accessories;
- Adaptation firms; or
- Online purchasing.

3.3.4.6 Discussion

Little research has evaluated the use of additional mirrors to aid people with restricted neck and trunk movement. In an Australian study, Paine and Henderson (2001) examined whether additional mirrors enabled drivers to reliably see children behind vehicles. They found that auxiliary mirrors "do not provide sufficient coverage or clear enough images to enable drivers to reliably see to the rear of the vehicle". This suggests that mirrors might not be sufficient in showing drivers children or low level objects such as bollards or kerbs behind the vehicle. The findings from the literature review suggest that while the mirrors might be useful for assisting in reversing and lane changing manoeuvres, they provide little help when drivers are faced with awkward junctions.
3.3.5 Other devices

3.3.5.1 Blind spot systems

The detection of objects in a vehicle’s blind spot may be assisted by more advanced blind spot systems than blind spot mirrors. At present there are several different types of technology available the current leading ones include:

1. A passive radar-based system with LED lights in the side mirror to indicate the presence and relative location of an object in a vehicle’s blind spot.

2. A digital camera mounted under a vehicle’s side mirror. By using image recognition technology it alerts the driver to a vehicle in their blind spot by illuminating a warning light mounted on the bottom of the vehicle’s A pillar.

3. A powered side mirror which sweeps out to show the vehicle’s blind spot when a driver indicates to change lanes or presses a button to activate. After a few seconds (during which time the driver would change lanes) the mirror returns to its original position.

4. A rear view camera. A bumper mounted rear-facing camera that continuously transmits images of the traffic behind the driver. This is usually displayed by means of an LCD screen in the vehicle, but can be an embedded screen inside the centre rear-view mirror.

However, it should be noted that these advanced systems are largely US developed and marketed, and are as yet still uncommon even in the US vehicle fleet. In the UK, they are virtually nonexistent, although it is possible that their market penetration might increase as the technology further develops. As such, none were explicitly evaluated as part of this project.

There are a few possible issues concerning their use on UK roads:

- With the exception of the powered side mirror, all systems increase the amount of visual information inside the vehicle. As such, they may increase the visual demand / potential for distraction to a driver. As has been mentioned elsewhere in this report, increasing the amount of visual demand for a driver can be a safety issue, especially in complex traffic situations, so the possible benefits of such systems need to be weighed against the probable negative consequences from increasing the amount of visual information.

- With the powered side mirror, although less distraction/visual demand is likely, the system may slightly change the nature of the driving task. For instance, it is generally taught that a UK driver should “mirror, signal and then manoeuvre”, however this system requires a driver to “signal, mirror and then manoeuvre”. Although this may seem a small change, it would involve modifying a driver’s over-learnt (i.e. repetitively practiced until the action is automatic) behaviour. Equally, there may be unexpected side effects from the side mirror moving position upon an indicator being activated; for example, it may reduce a driver’s awareness of the traffic environment around a vehicle (in which the driver maintains a continuous mental picture of the objects in the road in front and behind their vehicle). Finally, during some driving tasks the mirror may move inappropriately (e.g., if turning right at a T-junction or when reversing a driver would generally not want to have their side mirror automatically moved).

9 http://www.blindspotsystems.com
Of course, these are only speculations that are informed by more general research findings from similar in-vehicle advanced systems. However, it is stressed that such advanced blind spot devices should be evaluated with respect to such issues before they are widely available in the UK.

3.3.5.2 Reversing lens

Wide view, or reversing lenses use the ‘Fresnel Principle’ to give a much wider view of people and objects to the rear of the vehicle in the area that would normally be ‘blind’ to the driver. The lenses are designed to make reversing manoeuvres such as parking in a tight space easy for drivers without having to turn their heads (seen via the rear view mirror). The literature revealed two different types of reversing lens; one which is attached to the rear window by means of a clip, and the other (more common type) which adheres directly to the rear window (the latter can be seen in Figure 21). Like mirrors, reversing lenses can be purchased in car accessory shops, online or through certain adaptation firms for between £6-12.

![Figure 21 ‘Stick-on’ reversing lenses](image)

Previous research conducted in Australia evaluated both the ‘clip-on’ and the ‘stick-on’ lenses (see Henderson & Paine, 2001). The driver evaluations of the ‘clip-on’ reversing lens revealed that drivers were not satisfied with the performance of the device for several reasons. Firstly, it was found that the image produced in the lens was too small and distorted. Furthermore, it was found that the optimum location of the device for image quality resulted in the normal view to the rear being obscured. Evaluations of the ‘stick-on lens’ revealed similar findings; drivers found that the images tended to be distorted and fuzzy, and that the lens became ‘milky’ at certain angles of sunlight. Furthermore, it was found that when trialled on sloping rear windows, the ‘stick-on’ lenses were ineffective.
4  Phase 3: User survey

4.1  Aim
The aim of the user survey was to explore the safety and reliability of devices from the point of view of people who had been using them, or who might benefit from using them. It also provided an insight into the needs and concerns of people who feel that the available technology would not adequately compensate for their disability as well investigating how and in what situations such devices could assist.

4.2  Method
Participants were recruited via several different organisations which were contacted by TRL. The participants were current drivers, provisional licence holders or those who had stopped driving temporarily or permanently. The user survey involved 15-30 minute telephone interviews with drivers who experience, or experienced in the past, observation difficulties whilst driving due to movement restrictions to their neck or trunk. A topic guide was followed which covered issues relating to observation devices with the aim of fully understanding different user perspectives.

4.2.1  Recruitment of volunteers
Several organisations were contacted and asked for their help in recruiting volunteers. Organisations which assisted included the following (for the complete list see Appendix B):

- Large disability and motoring magazines such as ‘GEM Motoring Assist’ and ‘Disability Now’ magazines;
- Disability associations or charities such as Leonard Cheshire, Motability and Blue Badge Network; and
- Other organisations such as Mobilise, Group of Advanced Motorists, Age concern and the Forum’s Mobility Centres.

Disability and motoring magazines were asked to recruit participants by placing advertisements in their magazines calling for volunteers to participate in the survey (see Appendix C for an example advertisement). Similarly, some disability organisations put an advertisement on their website or in their monthly/quarterly newsletter asking members to volunteer. Other organisations offered to help by sending out individual letters or emails to some of their members and three of the Forum’s Mobility Centres also put out leaflets at their Centres. In all of the advertisements and leaflets circulated via the organisations, volunteers were asked to contact TRL to book a suitable time/date for an interview.

4.2.2  Topic guide
A topic guide was developed for the interviewers to use as an aide memoir during the telephone interviews (see Appendix D). The topic guide was devised with the view to cover issues that might be related to problems with observations while driving as well as to gather some background information about the participants, their condition and type of adaptations they use (if applicable). More specifically, the topic guide covered the following issues:

- The type of technology currently used;
- Advice received before choosing a device;
- Whether DVLA had been informed/consulted;
Situations in which drivers used or needed to use a device;
Difficulties the driver had in fitting or using devices;
Incidents/accidents which may be related to the devices;
Possible avoidance of incidents/accidents with devices;
Accessing the information, e.g. viewing camera screens;
Safety of using devices;
Reliability of devices, e.g. whether they failed in service;
Whether devices compensated for impairment; and
Retro- or factory-fitted (considerations at purchase).

4.2.3 Analysis method
A framework technique (Ritchie and Spencer, 1994, as described in Ritchie and Lewis, 2003) was used to manage and analyse data from the interviews. This technique required thorough and systematic analysis to ensure that the interpretations were based on the data collected rather than preconceptions or assumptions. Notes were made under key themes or topics which applied to all interviewees, such as affects on driving habits and difficulties with certain driving tasks. This enabled recurrent as well as exceptional information to be highlighted between and within interviewees.

4.3 Results

4.3.1 Volunteer characteristics
A total of 40 volunteers were interviewed (see Appendix E for the breakdown of medical condition, driving status and whether devices are used). They included 34 who were still driving, 16 of whom did not use an observation device.

Eleven of the 18 volunteers who used an observation device used a panoramic mirror (eight in combination with another device such as reversing lens or blind spot mirrors). Three used factory-fitted auditory reversing sensors, two retro-fitted reversing sensors, and another used a factory-fitted reversing camera. Another three volunteers used only an additional mirror: one a self-made mirror attached to the dashboard; one a blind spot mirror attached to the dashboard; and the third attached to the door mirrors. Three of the volunteers were learning to drive and all three used a panoramic rear view mirror. The remaining three of the 40 volunteers had stopped driving, either because they did not feel safe or it was becoming too difficult.

The interviewees’ medical conditions ranged from congenital to acquired and functional ability also varied with some volunteers reporting that they had limited movement in their neck and/or trunk. For some it was more a case of experiencing pain or discomfort whilst undertaking some driving tasks. There was also a difference in whether a condition was stable, progressive, or changeable daily. Generally, it was perceived that the treatment options available to the volunteers were not thought to address mobility, but were rather to overcome pain.
4.3.2 Effects on driving, habits and ways of coping

4.3.2.1 Reversing

Reversing was universally experienced by volunteers to be affected by their condition and seemed to be the main concern along with negotiating junctions. This would seem to be supported by the incidents described by six of the volunteers, mostly involving near misses or minor damage from colliding with static objects when reversing, particularly when parking (see Case Study 1 as an example).

Case Study 1:
The interviewee was diagnosed with Ankylosing Spondylitis which caused stiff joints and bones in the shoulders and neck. Prior to purchasing a vehicle with a manufacturer-fitted reversing camera, the interviewee was involved in an incident. It was admitted that this was his fault because he could not see. He was in a back lane, with a narrow section, and another vehicle approaching from the opposite direction who did not reverse to allow the interviewee to pass. The interviewee described how he took a glance through his nearside mirror and reversed into what he thought was a grass bank which was in fact a stone wall, causing damage to his vehicle.

However, it was recurrently reported that the interviewees were able to compensate by using their mirrors (standard as well as additional), and therefore did not feel that reversing presented a problem to them. For example, some described how they tilted the door mirrors down to an angle where they could see the pavement in order to reverse. Less commonly, accounts were also given of efforts to avoid carrying out reversing manoeuvres, for instance by trying to drive into and out of a parking space forwards. Another coping mechanism was for volunteers to ask others (either inside or out of the vehicle) to assist them with a reversing (and other) manoeuvres, for example by giving information about distances.

4.3.2.2 Junctions

Difficulties were commonly experienced at junctions, particularly those which had a ‘difficult’ angle (involving a turn of more than 90 degrees). Those who did not feel that their observations were affected at junctions tended to describe twisting or turning their body or leaning forwards whilst others mentioned positioning the vehicle to enable them to see. Whilst there was a trend for volunteers to ask for the advice of others (on some occasions even admitting to be unable to drive without someone else), less commonly it was reported that they did not want to become dependent on others or distracted.

Driving behaviour was also adapted in order to compensate for having difficulties observing left and right at junctions. More usually this would be by becoming more cautious and adopting a “creep and peep” approach, and less commonly by becoming more risky and “taking a chance”. Again, trying to avoid junctions, particularly those known to the volunteer to be awkward, was another slightly less favourable option. There was a tendency to adapt by turning left if it was not possible to see right and then performing a U-turn or turning around at the next roundabout. An exceptional account was given of adapting to observation difficulties by taking off the seatbelt in order to lean forward as well as twisting more easily.
4.3.2.3  **Blind spots**

Blind spots were not perceived as such a problem for most volunteers, but where these were related to junctions, a couple of incidents were reported (see example Case Study 2).

**Case Study 2:**

The interviewee has Cerebral Palsy and explained that as a result the left side of her body is weaker than her right. Due to degeneration in the neck area, she has difficulties turning to look to the right. Although the interviewee has a panoramic rear view mirror and blind spot mirrors on the door mirrors of her car, these do not seem to be of assistance at a junction. She described having a near miss incident when she pulled out from a junction to turn right and another was car approaching from the right. The interviewee considered that difficulties with her observations were a contributory factor in the incident.

4.3.2.4  **Three-point turns, lane changes/merge and roundabouts**

Three-point turns were also less commonly highlighted as a problem, though difficulties were overcome by avoiding performing such manoeuvres or by using their mirrors (standard and additional). One volunteer reported having an accident when performing a U-turn in the road and hitting a motorcyclist approaching from the right as they were unseen by the volunteer.

Lane changes, overtaking and merging into traffic were not considered to be a difficulty in the main. However, one volunteer reported that it was their main concern (they had a self-made mirror with an adjustable ball and socket joint mounted on the dashboard). Another had a near miss when changing lanes and did not see an approaching vehicle in the blind spot. This volunteer then purchased blind spot mirrors to attach to the door mirrors to try to address this.

Roundabouts were only mentioned by a few volunteers as causing them problems, generally because the traffic is considerably slower than at junctions, the angle is not so tight, and the driver is only required to look to the right rather than both ways. However, two incidents were described where the volunteer had pulled out in front of a vehicle approaching from the right due to not seeing them, and in one case resulted in a collision (neither of these volunteers had an observation device at the time nor since).

4.3.2.5  **Mileage and restriction of driving**

Typical weekly mileage ranged from two or three to 400 miles, with a mean of 116, median and modal values of 100. Seven of the 11 who explained that they had restricted their driving had observation devices to assist them with their observations. Driving was limited by reducing the total mileage driven, the length of each journey, the frequency of longer journeys or not driving in built-up areas or when their condition was worse. Although difficulties with observations were a contributory factor in this restriction, it appears that there are other inter-related factors, such as pain and a general effect on the body caused by the condition and even due to age or road traffic accident involvement. As highlighted above, driving was restricted in other ways however, including taking more time/caution/double checking, avoiding certain manoeuvres and junctions, changing planned routes if difficulties encountered, and adapting methods of parking.
4.3.3 Advice and information

DVLA state that “If you have had, or currently suffer from a medical condition or disability that may affect your driving you must tell the DVLA. You’ll also need to provide details if you develop a new condition or disability or one that has become worse since your licence was issued. Failure to notify DVLA is a criminal offence and is punishable by a fine of up to £1000.” A user of a device would therefore only need to inform DVLA if the use of the device was necessary and the individual would be unable to drive without it.

Table 3 shows that drivers with difficulties with observations tended to have informed DVLA about their condition but not necessarily that they are experiencing difficulties with observations. Awareness of the need to inform DVLA about the use of panoramic rear view mirrors also seemed to be inconsistent.

<table>
<thead>
<tr>
<th>Table 3 Driver information to DVLA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>About medical condition</strong></td>
</tr>
<tr>
<td>Informed DVLA</td>
</tr>
<tr>
<td>21</td>
</tr>
<tr>
<td><strong>That observations difficult</strong></td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td><strong>Using panoramic mirror</strong></td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td><strong>Using reversing sensor (retro-fitted)</strong></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td><strong>Using reversing sensor (standard)</strong></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td><strong>Using other observation device (e.g. reversing lens, blind spot mirrors)</strong></td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td><strong>Stopped driving</strong></td>
</tr>
<tr>
<td>1 (licence not revoked)</td>
</tr>
</tbody>
</table>

Reasons participants gave for not informing DVLA about their condition (and difficulties with observation) included:

- Unaware that they were supposed to;
- Condition was not thought to be severe enough;
- They did not drive much anyway;
- They did not think that the DVLA would be able to help the situation;
- They did not believe condition to be a safety hazard; and
- They were not asked.

An additional reason for not informing DVLA about the use of observation devices was that there was a belief that the vehicle was not ‘adapted’ as such and so there was no need. Even if the individual relied on a device, if it was available for any driver (particularly if it came with the vehicle as standard) it was not felt to be necessary to inform DVLA.

Some who had informed DVLA about their condition (and possibly their device) had not informed their insurance company. Although there could be issues with liability, individuals
had concerns that the premium would be increased, and one volunteer who had informed their insurance company had experienced this. However another reported that their premium had actually been reduced after notifying them about the use of a panoramic mirror. For those who had obtained their vehicle and insurance through Motability, it was usually felt that the insurance company would automatically be aware of their condition (and device).

Advice about observation devices was generally not forthcoming from DVLA (for those who notified the licensing authority about their condition and/or difficulties). Other sources of information were Mobility Centres, manufacturer magazine/car salesman, disability magazines/websites, Motability, Mobility Road Show, looking at others’ vehicles, and a rehabilitation disabled living course run by an occupational therapist at a hospital.

4.3.4 Type of devices currently being used

4.3.4.1 No devices

It is worth noting that there are potentially a lot of drivers with restricted neck/trunk movement with observation difficulties who are currently not using any device to assist. In this sample, 16 of the 37 currently driving (including those provisional licence holders) did not use an observation device. There may be a tendency for volunteers to concentrate on their pain or discomfort as safety is not a direct issue due to compensatory behaviour. It may be a case of experiencing difficulties rather than inability. There seems to be a difference between whether the interviewee felt assistance with observations whilst driving was essential (i.e. they are unable to drive without such assistance) and whether they identified that it might just be beneficial, with most seeming to identify themselves as belonging in the latter category.

4.3.4.2 Purchase of vehicle

Whether consumers considered observation difficulties when purchasing a vehicle seemed to be related to whether adaptations were necessary. For example, if adaptations were needed to control the car these tended to be the ‘top priority’. However, about half of the sample reportedly considered observation difficulties when purchasing their vehicle, occasionally as the main priority, but more likely along with other requirements. Aspects such as how adjustable the mirrors were and the visibility they afforded, overall visibility with the vehicle (seating position and height) were assessed by interviewees.

4.3.4.3 Range of devices

As well as making greater use of the mirrors which come as standard in a vehicle to optimise visibility, for example door mirrors with a convex section and those with additional mirrors attached, the following observation devices were used:

1. Reversing lens on back window (described in 3.3.5.2);
2. Small mirrors attached to rear view mirror with swivel joints;
3. Mirror clipped onto sun visor angled 45 degrees to right;
4. Blind spot mirrors attached internally or externally (as in 3.3.4.1);
5. Self-made mirror with ball and socket joint attached to the dashboard;
6. Manufacturer- and retro- fitted audible reversing or parking sensors (as in 3.3.3);
7. Reversing camera as in section 3.3.2 (and in Case Study 3 in section 4.3.4.7); and
8. Panoramic rear view mirror as in 3.3.4.3 (and in Figure 22 in section 4.3.4.6).
4.3.4.4  Mirrors
The first four devices listed above were all purchased from Halfords, on mail order or the AA, for approximately £5 each and were apparently easy to fit (mostly by the interviewee themselves) and durable. There was some concern that the additional mirrors and lenses took a while to get used to judging distances accurately due to a distorted view. In the case of the reversing lens the quality of the image and its durability seemed to depend on the price. There was also an uncommon concern that the positioning, particularly of the additional internal blind spot mirrors, was challenging to get accurate. One interviewee also found that vibrations of the mirrors caused difficulties in accurately assessing the image and induced nausea. Another interviewee reported previously using a mirror which spanned across the whole front of the car (purchased from the National Ankylosing Spondylitis Society.

4.3.4.5  Sensors
Three interviewees had purchased a vehicle with manufacturer- or factory- fitted audible reversing sensors, whilst another two had purchased an audible reversing sensor system to fit retrospectively to the vehicle. Although two felt that they had become dependent on the device, the other three interviewees currently using a parking or reversing sensor system claimed that they were able to drive without it but that it gave them confidence that they were “not going to hit something behind the car”.

The sensors all work by emitting a slow audible signal or beep which increases in speed or frequency the closer the sensors are (and therefore vehicle is) to an object. One interviewee explained that the volume could be adjusted in order that the signal could be detected even in busy road environments. One of the retro-fitted parking sensors also apparently indicated the distance using a traffic light step display system with five LEDs (yellow to green to red). No specific instructions were available regarding how to use the sensors (either manufacturer- or retro-fitted), but one of the retro-fitted systems came with assembly instructions from the local car shop where it was purchased (at about £20).

The retro-fitted system consists of two sensors which are attached to the rear bumper with adhesive pads. A radar circuit has to be created by connecting the wires to the reversing light. It was reportedly easy to fit and to remove to use in other vehicles, although the interviewee admitted that the wires sometimes become detached when putting things into the boot.

Generally there were no concerns about use of the sensors. Although one volunteer felt that the device sensed objects to the far left/right which were not obstructing their progress, it was generally felt that there were no false alarms or missed detections. One of the retro-fitted systems had been replaced after a couple of months as it had become “temperamental” and another interviewee had experienced vandals deliberately blocking the sensors with something; it was not always noticed until the device was required. This interviewee also felt that the sensors were more sensitive than a driver would be without the device so that more space is left when parking than necessary, although admitted that this is something which the user must become accustomed to and amend their response accordingly.
4.3.4.6  Panoramic mirror

Figure 22 shows the themes that emerged from the interview data related to panoramic rear view mirrors, including fitting, use and concerns. Three volunteers had tried a panoramic mirror previously but had not continued to use one because they felt they did not need it (since purchased blind spot mirrors to attach to the dashboard), that it provided too much information, or that the image it provided was distorted.

Figure 22 Panoramic rear view mirror
4.3.4.7  Reversing camera

Case Study 3: reversing camera

Interviewee with Ankylosing Spondylitis and has 20% neck movement to left compared to 80% movement to right. He purchased a vehicle with an in-built reversing camera which has the screen on the dashboard. This can be switched off if it is not needed by other drivers of the vehicle and can only be used when the vehicle is in reverse. The interviewee only uses it for parking (rather than general reversing manoeuvres). He explained that it took time to get accustomed to what the image represented, and occasionally gets water or dirt on the lens which has to be wiped off. No training was given but the salesman told him how it worked. The interviewee experienced no difficulty in using it and found it very easy to use. It has improved his confidence when reversing and he has had no accidents/incidents since using the camera (compared to several before). He has not considered whether it makes him a safer driver.

4.3.5  Desirable devices and reasons for not purchasing

Generally more information about observation devices was desired. Two of the three volunteers in the sample who had given up driving did so due to concerns over safety. Although they could not turn their neck at all, both expressed a desire to return to driving if a suitable device(s) could give them the confidence to do so. The third volunteer with Cerebral Palsy experienced pain in his neck when turning it and had given up driving after pressure from family. Although he had previously tried a panoramic rear view mirror which he found helpful for reversing and at junctions, he had found it particularly difficult at junctions to turn his head quick enough. None of these three volunteers were aware of any further devices which may assist them, though they would like to return to driving.

Interviewees described a number of devices which they would like to try, including some which are more unusual and highlighted as ideal rather than actually in existence. There were also a number of reasons for not purchasing a device and concerns over the use of such devices. This can be seen in Table 4.
Table 4 Devices and their perceived limitations

<table>
<thead>
<tr>
<th>Desirable devices</th>
<th>Concerns and reasons for not purchasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Any device</td>
<td>• Unnecessary as condition not severe enough or safe without</td>
</tr>
<tr>
<td></td>
<td>• Uncertainty over where to purchase</td>
</tr>
<tr>
<td>• Audible parking sensors (very popular)</td>
<td>• Unable to retro-fit so defer decision until purchase next car</td>
</tr>
<tr>
<td>• Also LED sensors with lights to indicate distances from objects when reversing</td>
<td>• Too expensive</td>
</tr>
<tr>
<td></td>
<td>• Unable to obtain through Motability</td>
</tr>
<tr>
<td></td>
<td>• Concerns over whether work/compensate for impairment</td>
</tr>
<tr>
<td>• Cameras to look left/ right/ reverse (mentioned often)</td>
<td>• Expensive to purchase/fit</td>
</tr>
<tr>
<td>• Camera on front bumper with joystick control for junctions</td>
<td>• Distraction caused</td>
</tr>
<tr>
<td>• Additional mirrors including blind spot mirrors, door mirrors and panoramic rear</td>
<td>• Panoramic mirror only help look behind not left/ right</td>
</tr>
<tr>
<td>view mirrors (commonly mentioned)</td>
<td>• Positioning of mirrors</td>
</tr>
<tr>
<td>• An electric mirror on passenger side to operate as needed</td>
<td>• Blind spot mirrors fall off</td>
</tr>
<tr>
<td></td>
<td>• Distorted image of panoramic rear view mirror in particular</td>
</tr>
<tr>
<td></td>
<td>• Mirrors cause obstruction</td>
</tr>
<tr>
<td>• Reversing lens</td>
<td>• Distorted or insufficient image</td>
</tr>
<tr>
<td>• A device to indicate speed of cars approaching from side(^\text{10})</td>
<td></td>
</tr>
</tbody>
</table>

4.4 Implications for in-depth evaluation of devices

1. Panoramic mirrors were most frequently used by drivers with restricted neck/trunk movement and so the findings from the in-depth review may have a great impact. It was also reported by users that they had to get accustomed to distortion, which could be investigated. However, the use of additional mirrors is already officially coded on the driving licence (although this was not known by all).

2. Manufacturer-fitted devices, such as reversing cameras or even the convex section of the door mirror, could be used by those with restricted function to assist their observations and relying on them to make observations. There is an issue about whether their intended purpose is as an additional aid/asset rather than to be relied on solely to compensate for impairment.

3. An audible reversing or parking sensor seemed to be regarded highly, including by the three interviewees who currently used such a system although there seemed to be some reliability issues with the retro-fitted device.

\(^\text{10}\) It should be noted that there is no evidence that this device is currently available, but was on an interviewee’s ‘wish list’.
5 Devices to evaluate in-depth

5.1 Selection of devices

The selection of devices for the in-depth evaluation took into account the views expressed in the consultation and user survey and the potential usability issues that were identified by TRL as part of the review.

According to the user survey, the key areas of difficulty for people with restricted neck and trunk movement were reversing and junctions (especially with sharp angles). Therefore, it seemed appropriate to focus on these areas in the evaluation.

5.1.1 Junction camera

Junctions are the highest risk manoeuvre that is impaired by restricted neck and trunk movements. Reversing accidents will generally only result in minor damage to vehicles, while accidents at junctions are potentially much more serious. Although junctions were mentioned as a problem by many people in the user survey, no one mentioned a device that they used to compensate for the difficulty. The compensation strategies used such as “peep and creep” and “taking a chance” are also potentially hazardous.

Therefore, it seemed appropriate to evaluate a junction camera system as this was the only device designed specifically with disabled users in mind and has the greatest potential to aid the driver in a junction situation. It was also felt that as a relatively new idea that the findings of the evaluation may be able to feed into the design of products as it developed, helping to provide more effective products in the long run. Junction cameras were also the subject of the most serious concerns raised during the consultation process, such as whether a junction camera allows an accurate judgement of speed and distance, whether drivers are able to access the information quickly enough and whether the devices are suitable for junctions with acute angles.

5.1.2 Reversing aids

Most of the other devices identified were designed to assist with reversing and parking. This includes sensors, cameras, reversing lenses and additional mirrors. There was thought to be quite a lot of variety in this area and different concerns for different systems.

5.1.2.1 Panoramic mirror

The most popular reversing aid used by those who took part in the user survey was the panoramic rear view mirror, which users found helpful and in some cases participants stated that they could not drive without it. The use of additional rear view mirrors is currently included as an information code on the license. The implicit assumption by drivers is that mirrors are therefore ‘acceptable’ as an aid to people with restricted neck and trunk movement. However, concerns were still expressed in the consultation that the convex nature of the lens may provide a distorted view. Therefore, there were several strong reasons to include them in the evaluation.
5.1.2.2 Reversing lens

A reversing lens was used by one person who took part in the user survey. The literature relating to this device included a formal evaluation by an academic research team. This evaluation highlighted several concerns which included the obstruction of the normal view out of the rear, a small and often unclear image and unreliability unless mounted vertically. On the basis of this evidence this device was not recommended for further evaluation as it seems apparent that it is not effective.

5.1.2.3 Reversing sensors

Some users expressed an interest in audible reversing sensors but were not aware of other devices (e.g. reversing cameras) that might be useful. It was considered possible that users were aware of the audible reversing sensors with increasing availability as a standard feature in new vehicles. Reversing cameras are also becoming more popular and are available as an additional feature in some new high-end vehicles.

Of the reversing sensor options, there were particular concerns relating to each type; one such concern was that when using the audible alert, it may be difficult to interpret the results in terms of distance and to recognise the nature and position of the object. Visual alerts with a distance and positional display or reversing cameras overcome some of this problem but there may be a modality conflict when performing the reversing manoeuvre as the driver tries to look out of the vehicle and at the display at the same time. This concern was also expressed during the consultation as potential distraction. It was therefore recommended that the evaluation included two types of reversing sensor, one that provides an auditory warning and one that provides a visual display including a distance and position indication.

The combination of a visual and auditory feedback method was thought to potentially alleviate the modality conflict problem to a certain extent as drivers still receive feedback even when they look away from the visual display. As reversing cameras are often integrated with a reversing sensor system, it was suggested that an integrated system would make a better subject for evaluation than a reversing camera alone.

5.1.3 Blind spot mirrors

It was considered beneficial to include blind spot mirrors in the evaluation of observation devices because they were commonly used by drivers with restricted neck/trunk movement to assist in driving tasks which they experienced difficulties with. There was concern expressed during the consultation phase that if a device is relied on then it should be included as an information code on the licence as well as concern over whether the devices are being used as they were intended to be. There was also thought to be benefit in investigating the suggestion that mirrors could actually create blind spots of their own.

5.1.4 Gooseneck mirrors

Inclusion of the gooseneck mirrors in the in-depth evaluation was felt to be valuable due to them commonly being recommended by staff at Mobility Centres for drivers with restricted neck or trunk movement.

Table 5 shows a summary of reasons for inclusion of these devices in the in-depth evaluation.
### Table 5 Devices for further evaluation

<table>
<thead>
<tr>
<th>Device</th>
<th>Reason for further evaluation</th>
</tr>
</thead>
</table>
| Junction camera                                | • Junctions are a high risk situation (particularly for this driver group)  
• Only system designed to help people negotiate junctions specifically  
• Many potential usability issues identified in the review and through the user consultations |
| Panoramic mirror                               | • Currently most widely used device  
• Implicit assumption by users that it is acceptable therefore a good benchmark for evaluation  
• Potential distortion of image |
| Reversing sensor with auditory warning          | • Becoming available as standard with many new vehicles  
• Potential issues with using it to judge the distance, position and nature of obstacles |
| Reversing sensor with visual indication of distance and position | • Gives more information of the distance and position of obstacle compared to auditory warning  
• Potential distraction/modality conflict may make it difficult to use for reversing |
| Reversing camera with auditory warning          | • Potential to overcome drawbacks of reversing sensors with auditory/visual displays  
• May be difficult to learn how to use it to control the vehicle when reversing  
• Consultation expressed concern over camera based systems |
| Blind spot mirrors                              | • Commonly used  
• Potential creation of blind spots |
| Gooseneck mirrors                              | • Commonly recommended by Mobility Centres |

#### 5.2 Vehicle and fitting of the devices

A Ford Focus Zetec, test vehicle was used for phase 4a and phase 4b. It had the limitation that measurements only apply to one type of vehicle; however it was beyond the scope of this project to test a range of vehicles.

The adaptation company, PB Conversions supplied a panoramic mirror and fitted the following devices to the vehicle.

- Junction camera (Panasonic)
- Reversing camera (Panasonic)
- Reversing sensors with audible and visual display (Ex Vision)
- A two-way mirror and junction box for operation of the junction and reversing camera systems.
Rectangular blind spot mirrors were purchased from Halfords (manufactured by Summit Automotive) and two gooseneck mirrors, manufactured by Herbert Richter GMBH and Co. were obtained.

It should be noted that all of these devices were fitted to the vehicle retrospectively and that there may therefore be particular issues with manufacturer-fitted devices which could not be addressed within this project.

5.3 Restricting range of movement

Several of the evaluations required able volunteers to be used in lieu of disabled participants for practical, experimental and ethical reasons. This required their movement to be restricted to simulate the effects of neck/trunk movement impairment.

Several methods of artificially restricting movement were investigated. One possibility was the “third age simulation suit” developed by Loughborough University, designed to simulate the effects of old age including restricted joint movement. A member of the project team travelled to Loughborough to inspect the suit and determine if it was a viable option for use in this project.

The suit was not considered suitable for the following reasons:

1. The restriction created in the neck and truck was not sufficiently severe. The restrictions are made of fabric, foam and Velcro and it is possible to overcome the restriction and maintain a full range of movement using additional effort to push against the restraints. Different participants could do this to different extents and it would therefore introduce more variance into the results.

2. It is a full body suit which includes restrictions at the elbow, wrist, knee and ankle. It was not possible to remove these elements and just use the neck and trunk portions without significant additional cost to adapt the suit.

3. The suit is heavy, cumbersome, hot and uncomfortable to wear. It is difficult to get on and off which would limit participants’ ability to take regular breaks from wearing it.

4. The cost was prohibitive

An adjustable rigid neck brace was ultimately chosen as the neck restriction method as this provides severe restriction, is readily available, low cost and can be easily removed and replaced. It was considered whether a back brace should also be worn to simulate trunk movement but this was eventually rejected as it would need to be worn under the clothes and is more intrusive and difficult to put on correctly and remove. As an alternative, all participants wore seat belts and were instructed to keep their backs against the vehicle seat during the experimental conditions which were ‘restricted’.
6 Phase 4a: Expert heuristic evaluation

6.1 Aim
The aim of this phase was to evaluate the systems in terms of their usability and effectiveness, with a particular focus on issues that will not be explored fully in the user testing.

6.2 Method
In order to define the scope of the testing relevant human factors design guidelines were reviewed including:

- The US DoT Human Factors Design Guidelines
- The TRL HMI checklist
- The Australian Task Auditing checklist
- Key human factors texts e.g. Sanders and McCormick (1992)

This was compared to the content of the field of view measurements, safety inspection and user trials to identify areas that were not covered in other tasks. These elements were used to develop a usability questionnaire for the assessment. This approach ensured a complete and thorough consideration of issues.

The usability questionnaire was used as a tool to structure the observations made by two professionally qualified TRL human factors experts. In order to reduce subjectivity, the two assessors conducted their assessments independently. After the assessment of each of the seven devices, the assessors met to discuss and synthesise the results. Any differences in opinion were highlighted and investigated.

In addition, a variant of the junction camera with a dashboard mounted, rather than mirror mounted, display was also assessed. The current project intended to assess a reversing camera with a dashboard mounted screen but it was not possible to have one installed in the vehicle so a rear-view mounted screen was used for all camera systems (junction and reversing). It was decided that there was value in assessing the dashboard mounted screen. This was conducted using a system available in another vehicle at one of the mobility centres. This system has a dashboard mounted black and white screen which was used to display images from junction cameras and a reversing camera. The assessment concentrated mainly on the system display in comparison to the rear-view mirror mounted screen (also assessed) although some observations were made in relation to the junction camera system itself.

6.3 Analysis
This assessment produced qualitative information relating to potential usability issues of each device. Once the independent assessments were synthesised, the results were written up as a list of issues for each device and a discussion of the implications each issue could have for users who suffer from restricted neck/trunk movement. The results of the assessment therefore focus on negative aspects of the designs primarily. Where appropriate, implications for people with other disabilities were also considered.
6.4 Results

6.4.1 Overall
For all the devices evaluated, there was a lack of documentation/instructions. It is thought that, although operation of the devices should be reasonably intuitive, the lack of instructions may result in inappropriate adjustment, maintenance and use.

6.4.2 Panoramic mirror
The panoramic mirror is designed to replace a standard interior rear view mirror. It is larger and has a convex surface which affords a wider field of vision to the rear and sides of the vehicle. The mirror is designed to aid drivers with general rearwards observation and with reversing and overtaking in particular.

The key concern with this mirror is that the nature of the convex surface distorts the image. Objects viewed near the centre of the mirror appear smaller and further away and objects viewed at the edges of the mirror appear larger and therefore closer. This effect may make it difficult for people to judge the distance to objects and the position and speed of other road users. This has implications for the safety of pulling out, overtaking and reversing manoeuvres. Users with restricted movement have a disadvantage in that they cannot turn to verify what they see in the mirror. This limits the extent to which users may learn to interpret the images accurately.

The curvature of the mirror also results in an overall worse view of the area directly behind the vehicle. As the view from the rear screen is in the centre of the mirror it is smaller overall than when viewed in a standard rear view mirror and it is therefore harder to distinguish between objects. This may make some tasks more difficult when compared to using a standard mirror.

The wide view afforded by the panoramic mirror has the consequence of providing a very clear view of the interior of the vehicle. The passenger seat and the entire rear seat are visible. This may cause a distraction to the driver, particularly if they are carrying passengers. However, some users may find it an advantage to be able to see children travelling in the rear seats.

The physical size of the mirror presents some problems. Firstly, it restricts the use of the sun visors on both the driver and passenger sides of the vehicle. If the sun visors are lowered they obscure the outer portions of the mirror. If drivers feel unable to use the visors so they can maintain their rear vision they will suffer from the effects of glare in some circumstances. The wider field of view and size of the panoramic mirror also increase the propensity for glare reflected from the sun, street lighting and traffic.

Secondly, the size of the mirror also means that it obscures a greater percentage of the front field of view than a standard mirror. This would not present a problem in most instances because the mirror is high up but it may obscure some overhead signage, such as gantry signing on the motorway. Users with restricted movement are likely to be less able to compensate for this by movement in their seat.
6.4.3 Reversing camera

The reversing camera is designed to present drivers with an enhanced view directly behind the vehicle. The system assessed consists of a camera mounted above the rear bumper and below the vehicle number plate and a rear-view mirror mounted colour display screen.

Having the display mounted within the interior rear view mirror is beneficial because it does not require dashboard modification and places the display in a convenient position for use. However, the use of the mirror as a video screen restricts use of the mirror during normal driving. The example assessed has a heavy tint and this impairs normal rear view. The view is lower contrast than a standard silver mirror and it is therefore more difficult to distinguish objects. This problem is particularly pronounced in dark conditions.

The quality of the image is generally adequate for objects close to the vehicle that would be relevant when reversing. However, quality is degraded in some bright conditions. When the sun is shining into the camera the image suffers from light halo and pillar effects which make it difficult to see objects (Figure 23). Generally bright ambient light can also make it difficult to see the image due to washout and the range of brightness adjustment is not sufficient to compensate for this.

There is a small amount of image distortion such that objects appear to be further away than they are in reality. This is likely to be caused by the use of a slightly wide angle lens in order to increase the camera’s field of view. The addition of a reversing sensor mitigates the risk of striking objects due to distortion as it should warn the driver before a collision occurs.

There is some risk that using the reversing camera may capture the driver’s attention during reversing manoeuvres such that they don’t maintain awareness of the situation around the vehicle and may not notice other road users approaching.

The reversing camera is automatically activated during reversing and this makes it very easy to use. The view provided is superior to the view from the normal rear view mirror as it is wider and unobstructed by the vehicle itself. This means that low objects can be easily seen.
Generally the device presents only a few usability issues, the largest issues are related to the display. The issues highlighted apply to the particular system assessed. A wide range of reversing camera systems are now available and other products may not have the same problems.

6.4.4 **Blind spot mirrors**

Blind spot mirrors are designed to provide a view of the area around the rear wings of the vehicle that is often not visible in the normal interior rear view mirrors and door mirrors (the "blind spot"). View of this area is particularly important when changing lanes so that the driver can be sure they do not pull into the path of a hidden vehicle.

Blind spot mirrors are available in many incarnations. Those assessed in the project were rectangular mirrors designed to be mounted in the inside bottom corner of each door mirror. The surface angle of the blind spot mirror is adjustable in the horizontal plane by pivoting the mirror around a central axis. This allows users to customise the view to their particular vehicle and needs. The surface of the mirrors is slightly convex to provide a wider field of view.

Use of the mirrors may impose additional visual demand on the driver because they present a wide view within a small space and the image is slightly distorted. There is a related concern that the information provided by the mirrors is difficult to interpret in terms of the position of objects. Fine adjustment is difficult and the product may engender a false sense of security as the user may incorrectly assume that all blind spots are eliminated even if the mirrors are not fitted or adjusted correctly.

6.4.5 **Junction cameras**

The junction camera system assessed was designed specifically for drivers who have restricted movement which affects their ability to make observations at junctions. The system consists of two cameras which are mounted on either side of the vehicle on the inside driver and passenger door sills. The camera images are displayed via a screen integrated with the interior rear view mirror. The user controls the camera view (left and right) using buttons on the rear-view mirror casing.

The display screen is the same as that used by the reversing camera. Therefore, all points relating to the display made in section 6.3.3 apply also to the junction camera system. This includes restriction of normal rear view and problems with glare.

One potentially serious problem with the design of the junction camera system is the compatibility between the controls and the view displayed. The rear-view mirror display has three buttons in a horizontal grouping on the bottom of the casing. The buttons are labelled “1”, “2” and “3” from left to right (see Figure 24). Button “1” (i.e. situated leftmost of the three) activates the right camera view and button “2” (i.e. the centre button of the three) activates the left camera view. The location coding of the control buttons is therefore opposite to the location of the views they activate (i.e. the left button activates the right camera and vice versa)\(^1\). This makes it highly likely that users will select the wrong view.

\(^1\) This may be a particular feature of the installation for this project. The rear-view display would not normally have three cameras wired into it and this may have dictated the control arrangement.
The severity of this problem is compounded by the fact that there is no feedback, except for visually comparing the image to the view from the window, as to what view is currently displayed.

Figure 24 Controls, reversal and distortion of junction camera view

The situation is further confused because the image is reversed (see Figure 24) so that the door frame and door mirror that can be seen in the video image are the same orientation as the view from through the window on the opposite side (i.e. the left camera view display looks like the view from the right window in terms of the position of the door frame and mirror). Therefore, the user may easily mistake which view they are looking at. This has serious safety consequences as the driver could make faulty judgements about whether to pull out or not. Drivers with restricted movement may not be able to make the comparison between the camera view and the real view and may have no idea they have made a mistake. The fact that the image is reversed may have consequences in itself for usability when making driving decisions.

The quality of the image provided by the cameras is somewhat lacking which limits the driver’s ability to see and recognise objects at a distance, particularly if they are small (such as a cyclist) or contrast poorly with the background. The cameras use a slightly wide angle lens that causes some distortion.

The view of the cameras is partially obscured by the door mirrors and their position and angle are fixed. The driver therefore cannot adjust them to maximise their vision of the road and although the field of view of each camera is quite wide there are likely to be some examples of junctions which are difficult to negotiate confidently.
The cameras are mounted inside the vehicle looking through the driver and passenger side windows. Rain, frost, dirt or misting on the side windows all adversely affect the view provided.

Use of the junction cameras adds extra tasks to the driver workload as they have to activate the camera when approaching the junction, switch views and turn off the system after the junction. When the display is activated during normal driving it further reduces the normal rear view and may distract the driver.

Under time pressured conditions (as is often the case at junctions) and with additional workload drivers are even more likely to mistake which button to press and which display is viewed.

### 6.4.6 Junction cameras – dashboard mounted screen

The issues with the rear view mirror mounted screen revealed during the expert heuristic evaluation of the junction camera and reversing camera systems prompted an assessment of a junction camera system which uses a dashboard mounted screen. The system is very similar to that assessed in the previous section in that it uses two interior mounted cameras to look left and right. It differs in terms of the method of control, which is automatic and associated with use of the direction indicators, and the method of display, which is a black and white dashboard mounted monitor (see Figure 25). The assessment focused on the usability of the display screen although some observations on the method of control were also made.

![Figure 25 Dashboard mounted screen](image)
conditions. The additional size of the screen area compared to the rear view mirror mounted screen is also an advantage. Objects therefore appear larger and easier to recognise.

The main usability problem is the lack of contrast and brightness of the image and the lack of adjustment range of these properties. The screen is insufficiently bright to be reliably seen in any level of bright daylight and requires additional brightness or shading to be made usable.

The screen is black and white which would be usable as a reversing camera where objects being observed are close to the vehicle. The black and white screen may also be adequate for use as a junction camera. However, a colour screen would be preferable as it would promote easier visual discrimination of objects from the background and is likely to be favoured by users.

Dashboard mounting of screens and many other in-vehicle systems can be problematic. The majority of dashboard space is usually consumed with various other vehicle controls, such as heating and air conditioning controls. This can often lead to inappropriate placement of displays (for example, low down on the centre console) which increase the chance of a driver being distracted. The junction and reversing camera systems are designed to be used in dynamic driving situations where the driver’s attention should be focused on the exterior of the vehicle. Therefore, it is even more important that the display is mounted suitably. Suitably mounted displays:

- Are close to the driver’s normal line of sight to minimise the transition time between looking at the display and looking back to the road.
- Do not visually obstruct the driver’s view through the windows, via the mirrors or of other controls and displays in the vehicle
- Do not physically obstruct access to any control, cause inadvertent operation of any control or cause conflict with any interior fitting.
- Are not prone to reflections, glare or wash-out in any lighting condition, including at night.
- Are not prone to cause glare to the driver or produce reflections on any vehicle windows or mirrors in any lighting condition, including at night.

Providing all of these conditions are satisfied, a dashboard mounted screen, for the purpose of a junction or reversing camera system, would be preferable to the rear-view mirror mounted screen assessed in this project. However, if they cannot be satisfied, the rear-view mirror mounted screen may be a preferable alternative.

The control of this junction camera system was set up such that the system is automatically activated when the indicators are activated. Switching on the left indicator activates the right camera view. Switching on the right indicator activates the left camera view. Automatic activation of a junction camera system may be beneficial, especially for drivers who use hand controls and may not be able to cope with an additional control action in the junction situation. However, the activation criterion for this system is completely unacceptable and would not allow a driver to safely negotiate a junction. Turning right requires the driver to look both ways and this cannot be accommodated in the current system.
Switching views indirectly by changing the direction of the indication would not be a successful strategy as there is a large system delay (i.e. it takes a few seconds after changing indication before the other camera view is displayed) in the change between different camera views. This may not give the driver enough time to make safe decisions at junctions and has the added disadvantage that it would result in confusing signals for other road users.

6.4.7 Reversing sensor with auditory warning

The reversing sensor installed on the test vehicle consisted of four ultrasonic sensors connected to an auditory warning system. The system provides a warning in the form of a repeated high-pitched tone when an object is detected in range. The frequency of the tone increases as a detected object moves closer to the sensors and becomes a continuous tone at the closest proximity. The system is activated automatically when the vehicle is put into reverse.

Generally this system is very simple and easy to use. It is automatically activated and uses the auditory modality which allows drivers to attend to the reversing task visually and listen for the warning at the same time without difficulty. The sequence of tones is intuitive as the perceived urgency of the warning is consistent with increasing proximity of the obstacle.

One potential issue was the interpretation of the different tones in terms of actual distance to obstacles. A user manual which describes the sensing range of the system and the zones associated with different tones would be a useful addition. The system was supplied and installed by an adaptations company so it is unclear if any supporting literature was supplied by the manufacturer. In this situation the adaptations company would need to pass on any user manuals to the vehicle owner and/or provide appropriate training.

The system has a tendency to provide slightly unreliable warnings in that “false alarms” are occasionally produced. In this situation the system warns the driver of objects that are not present or are irrelevant to the manoeuvre. Occasionally, the system detects an object initially and then does not continue to detect it. A lack of reliability in such sensor based products could have safety implications if a user is relying on the system to detect people and other vehicles. It is also likely to impair the utility of the system and reduce consumer satisfaction and trust in the product.

The warning tone used by this system is quite loud and easily recognisable. It would be suitable for most users, although some hearing impaired users may find the pitch too high or the volume too low. It would be a useful feature if these could be adjusted as this would allow users to customise it to their own needs and preferences.

6.4.8 Reversing sensor with visual warning

This reversing sensor employs a panel of LED lights to warn the driver about obstacles behind the vehicle. The light panel is situated centrally above the rear window of the vehicle and is designed to be viewed through the rear-view mirror during reversing. The light panel is split into two halves (left and right) and the lights on the appropriate side light up according to where the object is in relation to the vehicle. Objects directly to the rear of the vehicle produce a symmetrical warning on both sides of the panel. The initial warning of a detected object is a single yellow/orange light at the outermost edge of the panel. The numbers of lights increases with proximity and at the closest proximity, red lights are activated.
The system uses the same four ultrasonic sensors as that described in the previous section. Therefore, the comments made in section 6.4.7 regarding sensing reliability are applicable to this system.

The warning provided by the system is relatively easily understood although the visual warning does not portray the same level of urgency as the audible warning. As before, the system would benefit from accompanying literature that defines what is meant by each warning level in terms of distance to objects. Again, the system was installed by an adaptation company and no user manuals or other supporting literature were supplied.

In some complex situations, the use of another visual warning may overload the driver’s visual capacity. It relies upon visual attention being directed at it. Drivers tend to use all of their mirrors during reversing and may be concentrating on the door mirrors rather than the interior rear view mirror and so miss the warning. The display is not prominent or bright enough to alert the driver when their visual attention is engaged elsewhere. Therefore, it may be useful to help the driver judge the distance to known objects (e.g. the back of a garage) but not to alert them to unexpected hazards (e.g. an unseen low bollard). Watching for the warning may also prevent drivers from maintaining awareness of the situation all around their vehicle, such as detecting other vehicles approaching.

The lack of brightness of the display means it is also likely to be washed out in bright daylight conditions and the display properties are not adjustable.

6.4.9 Gooseneck mirrors

The gooseneck mirrors assessed consisted of a pair of small round concave mirrors mounted on short flexible necks. The mounting method of the mirrors is a rubber suction pad which can be attached to smooth surfaces such as glass. Gooseneck mirrors are available for drivers to use in a variety of ways. Their flexible neck is designed to permit a wide range of adjustment so that drivers can customise the view according their particular needs. For the purpose of this evaluation, the mirrors were assessed as a device to aid with making observations at junctions. Other potential applications, such as viewing the blind spot and reversing were not assessed.

The gooseneck mirrors were found to be extremely difficult to fit and adjust to provide a good view at junctions. The suction pad, although simple to attach, only adheres to perfectly smooth surfaces, which in the test vehicle (a Ford Focus) meant that it had to be attached to the windscreen or side windows. A lack of smooth surfaces would be a problem in many vehicles as the most common material for interior fittings is textured plastic.

The “flexible” neck is quite stiff and as such, a lot of force is required to adjust it. This often results in the suction pad failing and the mirror coming off of the windscreen. The process of fitting the mirror is physically difficult because of the depth of the dashboard in the Focus. This means that it is quite a stretch to reach the windscreen in order to fit and adjust the mirror and some people with restricted movement could find it extremely difficult and/or uncomfortable. It would be difficult for someone else to fit and adjust the mirror on the driver’s behalf as the view is dependent on the seated position of the driver, although this could potentially be achieved by leaning across from outside the vehicle or from the passenger seat. The same problems would occur if a driver wanted to finely adjust the position of the mirror during driving.
As well as being physically hard, it is difficult to achieve a good view with the mirrors due to obstruction by the vehicle’s A pillars. One possible position that gives a reasonable view of a junction is with the mirrors facing each other. However, in this configuration the mirrors have a tendency to reflect each other which creates blind spots and provides a confusing view. Some other potential positions of the mirrors result in the mirrors being placed on the windscreen in the driver’s direct line of sight which obstructs normal forward vision. The driver would be highly constrained as to where the mirrors could be positioned in their particular vehicle and this affects their effectiveness as an observation aid.

![Gooseneck mirror view obstructed by vehicle A’ pillar](image)

The image provided by the mirrors was also found to have several limitations. The convex surface of the mirror is designed to provide a wider field of view but does result in some distortion of the image. Objects viewed near the centre of the mirror appear further away and objects viewed near the edges of the mirror appear to be closer. The way the mirror needs to be adjusted dictates that the view of the junction is usually provided at the edge of the mirror. It is therefore displayed in the most distorted portion of the mirror. The size of the mirror and the wide field of view results in a large amount of information being displayed in a small space. Objects appear very small in the image and this may make them difficult to distinguish and recognise. This, and the distortion of the image, may adversely affect judgements about the distance and speed of other road users.

### 6.5 Summary of main findings

For use during reversing, four devices were assessed: audible reversing sensor; visual reversing sensor; reversing camera and panoramic mirror. The two reversing sensor devices have similar benefits and usability problems. Both have the potential to help the driver detect obstacles to the rear of the vehicle. However, both lacked user guidance regarding the meaning of the indications in relation to real distances. Both devices use the same set of sensors and therefore suffer equally from any sensor reliability problems. The visual reversing sensor has the additional problem that the display is not conspicuous enough to alert the driver and requires continuous monitoring which may distract the driver from other observations.
The reversing camera is also designed to allow drivers to see objects behind them but through using their vision rather than detection by sensors. The camera system has the advantage in that users can get more information on the nature and position of the vehicle than through the sensors. However, the system screen results in reduced quality of normal rear view and it may take the driver some time to get used to distance judgement using this aid.

The panoramic mirror differed from the other devices in that it was designed to provide an improved all round view rather than focusing on a specific area. There are two key usability issues with this device. Firstly, the image suffers from distortion, such that normal rear view is reduced and distance and speed judgement may be impaired. Secondly, a large quantity of irrelevant information is displayed, such as the vehicle’s rear seats.

The panoramic mirror is also a potential aid for viewing the vehicle’s blind spots. The wide field of view provided has the potential to give a good view all round the rear and rear wings of the vehicle. The usability issues described above apply equally for blind spot observations and reversing. Blind spot mirrors were also assessed. This simple device had few usability concerns except that the image is slightly distorted and drivers may find it difficult to interpret the image in terms of position in relation to the vehicle.

Two devices were assessed as observation aids for use at junctions; these were the junction camera system and gooseneck mirrors. There were quite serious concerns with both of these devices, especially as they are likely to be used in high workload and/or conflict situations. The biggest concern with the junction camera system was the ability to select the correct view and to determine which view is being displayed. Confusion over this has serious safety implications because drivers may make faulty manoeuvre decisions which could result in an accident. The quality of the image is inferior to that of the naked eye which may make it difficult to distinguish some objects, especially low contrast or small objects such as cyclists. Image quality is further compromised by either precipitation on the vehicle side windows or bright sunlight. In addition, the rear-view mirror integrated display results in decreased quality of normal rear view. A dashboard mounted screen may be a preferable alternative providing best practice can be followed for the position and mounting.

The gooseneck mirrors are limited by the difficulty of obtaining a good view of the junction. The position of the mirrors is constrained by the surfaces the suction pad will adhere to, the need to maintain good forward view and obstruction by the vehicle’s A pillars or other interior fittings. Given all these constraints, the image is very likely to have significant blind spots. Fitting and adjusting the mirrors is physically difficult and some users with restricted movement may find it impossible. The convex surface of the mirrors results in image distortion such that the ability to recognise objects, speed and distance judgement may be impaired.

In summary, usability problems were identified for all devices. The problems ranged in severity and the most serious concerns related to the junction camera system and gooseneck mirrors. All devices providing vision suffered from image distortion to a certain extent. The highest degree of distortion was seen in the gooseneck mirror and panoramic mirrors due to their curved surface. The reversing sensor and camera systems posed fewer usability issues.
7 Phase 4a: Assessment of range of vision/detection

7.1 Aim
The aim of this phase was to measure the sensing range/area of each device to provide a representation to compare to normal and restricted views (i.e. impaired driver without any observation aids).

7.2 Method

7.2.1 General approach
The normal view and the restricted view provided two important benchmark points which were compared to the view provided by each device. The “normal view” was a representation of what an unimpaired driver would be able to see using the car windows and standard mirrors from the driving seat and when wearing a seat belt. The normal view was representative of the view that a driver with normal/corrected to normal vision would have when motivated (i.e. when making an effort to see objects around the vehicle by moving their head and body as well as their eyes.) As such, it provided the best case scenario for how much a motivated unrestricted driver can see from the driving seat. However, a limitation was that while actually driving someone would not be able to make some movements as they could compromise control or forward view.

The “restricted view” (see Figure 27) was a representation of what the worst case impaired driver (i.e. virtually no head or trunk movement, but still with normal/ corrected to normal vision) can see using the car windows and standard mirrors from the driving seat while wearing a seat belt. This therefore provided the worst case scenario against which to test the devices.

The view/sensing range provided and any blind spots created by each device (“Device view”) were then mapped out and compared to the best and worst case benchmarks. Highly effective devices would therefore provide vision up to the standard of the best case/normal view or better without producing significant additional blind spots. This method also allowed us to identify any gaps in vision that remained when using the device.

![Figure 27 Restricted condition with rigid neck brace](image)
7.2.2 Observers

The view from a vehicle’s windows and mirrors is dependent on the driver’s exact position within the vehicle. This is determined by several different body characteristics. In order to provide a range for the best and worst case benchmarks, the measurements were repeated for the normal and restricted views using three different “observers” of different body characteristics. Sitting eye height and driver proximity to the steering wheel have the biggest impact on what can be seen from a vehicle therefore, these were the factors that were varied in the measurements.

The normal and restricted view were measured using three observers to represent the 5th percentile female, 50th percentile male and 95th percentile male driver seating positions. These are:

- 5th percentile female stature: 1505 mm = 4’11’’ [sitting height 795mm]
- 50th percentile male stature: 1740mm = 5’9’’ [sitting height 910mm]
- 95th percentile male stature: 1855mm = 6’1’’ [sitting height 965mm].

The volunteers (recruited from appropriate TRL staff) adjusted the seat and steering wheel to the recommended positions in terms of height, longitudinal position and seat back angle. All observers had good or corrected vision to the level required to have a driving licence (roughly equivalent to 6/10 distance acuity on a Snellen Chart). The restricted view for each observer was measured. In addition the unrestricted view for the 50th percentile observer was measured as an overall benchmark for unrestricted vision. The data was collected at the same time as for the blind spot mirrors and so the view afforded by the blind spot mirrors is distinguished from the normal view by an X symbol on the data recording sheet.

The field of view provided by panoramic and blind spot mirrors were identified as viewpoint dependent, therefore the three observers were also used for these measurements. Each observer adjusted the door mirrors and rear view mirror according to instructions given by the researcher. Blind spot mirrors were always set in the neutral position such that the surface of the mirror was flush with the outer casing. The vision afforded by the gooseneck mirror was tested using the perspective from the 50th percentile volunteer to give one example. The gooseneck mirror and therefore the range of vision can be adjusted according to the viewer. Other devices provide feedback independent of viewpoint so can be tested using a member of the project team as observer.

7.2.3 Measurement method

Measurements were made by marking a large grid around the vehicle which was parked on level ground. A test object was moved systematically around the grid and it was recorded where it could be seen/sensed and when it was occluded. The grid had more area to the rear and sides of the vehicle than to the front as forward vision is less affected by movement restriction and reversing and junctions were identified as problem areas during the user survey. The overall grid dimensions were 30m by 20m and the grid was split into 25cm x 25 cm squares. The car was positioned in the centre of the grid such that there was 5m of space to the front and 15m to each side as shown in Figure 28.
It was decided that the measurement of the vision/sensing range around the vehicle needed to take into account the height of the object. Because there may be regions around the vehicle where a tall object but not a low object could be detected, the measurement used test cylinders of three different heights.

The test objects were representative of real world objects:

1. 15cm – a high kerb with the potential to damage a vehicle
2. 80cm – a typical bollard or small child
3. 140cm – the height of a typical car or older child
Figure 29 shows the test cylinders and test vehicle on the marked out grid. All test cylinders were 25cm in diameter and painted yellow to ensure that they were conspicuous and easily distinguished from background objects. The measurements were converted into plan view scale drawings which were colour coded to show which heights of objects could be detected. As it was expected that low objects would be most difficult to see/detect, the colour coding represented the lowest object it is possible to see in the region.

7.2.4 Procedure

The procedure was to measure one 5m square (labelled with large letters) at a time. One researcher was present in the vehicle with the observer (or in the driver seat for permutations with no observer) with the data collection sheet (an A3 copy of Figure 28) and one researcher moved the test object around the grid. The in-vehicle researcher moved according to the square being tested so that they did not affect the observer’s view.

Starting with the lowest object, the observer outside the vehicle moved the object starting from the bottom left corner e.g. (A1a) and worked horizontally (e.g. A1a, A2a, A3a) until reaching the end of the row. They then moved to the beginning of the next row up (e.g. A1b). The researcher in the vehicle marked the squares where the object could be seen on the screen or by the observer. Squares where the object could not be seen were left blank12.

Having completed a square, the researcher outside the vehicle moved to the next square in the sequence. When all relevant squares were completed using the lowest object the researcher moved onto the next highest object and started again from the beginning of the grid. For this, only squares where the lower object was not seen needed to be tested as it was assumed that if the lowest object could be seen then all other objects would also be seen. The procedure was then repeated for the highest object.

A map showing the lowest object that can be detected in each square was produced by the researcher in the vehicle using a different coloured pen to differentiate between different height test cylinders:

1. Lowest object
2. Middle object
3. Highest object

Observation instructions were as follows:

1. Each observer was firstly asked to adjust the driving seat position according to the “Initial driving position and posture guide” which was provided by the researchers.
2. The observer was then asked to adjust the rear view mirror.
3. The observer then adjusted their side mirrors with the aim that when an object disappeared from the rear view mirror it appeared in the side mirror.

12 For the restricted permutations, areas that could be seen only in the blind spot mirror were distinguished from other areas using an X symbol of the appropriate colour. Areas that could be seen in the blind spot mirror and other mirrors or windows were distinguished using a I symbol of the appropriate colour.
4. The observer then adjusted the blind spot mirrors accordingly so they were in the neutral position.
5. The observer put on seat belt.
6. The researcher in the vehicle explained the task according to the permutation being tested:
   a. **Normal unrestricted view**: For each movement of the object say whether you can see it or not using normal car windows and mirrors. You may move in order to try and see it, e.g. bend forward, look over shoulder or twist but try not to make any movements that you would not be able to make while driving. For the purpose of this study, if you can see any part of the object, even if it is only small then it will be recorded as seen.
   b. **Restricted view (with blind spot mirrors)**: For this please put on the neck brace. Aim to make it tight enough that it restricts your movement but not tight enough to be uncomfortable. For each movement of the object say whether or not you can see it using normal car windows and mirrors. You may not bend or twist to try and see it, please try and keep your back against the seat. For the purpose of this study, if you can see any part of the object, even if it is only small then it will be recorded as seen. We also need to record what can be seen in the blind spot mirror so please say whether you can see an object in the blind spot mirror or just using normal mirrors and windows. If the neck brace becomes uncomfortable and you would like a break just say.
   c. **Panoramic and gooseneck mirrors**: For this please put on the neck brace as before. For each movement of the object say whether or not you can see it using the (panoramic or gooseneck) mirror. You may not bend or twist to try and see it, please try and keep your back against the seat. If the neck brace becomes uncomfortable and you would like a break just say.

7.2.5 **Analysis**

All measurements were drawn on the same scale so that it was possible to overlay the images to compare the size and shape of different regions. The normal and restricted views provided the best and worst case scenarios so could be used to judge whether the devices provide a sufficient view/sensing area to compensate for the worst possible impairment. This information can be used by assessment centres to make recommendations to individual clients based on the nature and level of their impairment. The results were also examined by TRL’s vehicle safety experts who assessed the risks associated with any blind spots which are still present when using the devices in terms of the types of accidents that might be more likely to occur.

7.3 **Results**

7.3.1 **Unrestricted vision compared to restricted vision**

The unrestricted field of view plot for the 50th percentile male shows that an average sized person with correctly adjusted mirrors and wearing a seat belt generally has a good all round view (see Figure 30). The view of the area approximately 2m directly in front and approximately 2.5m to the left hand side of the vehicle is slightly limited in that the lowest test object (15cm) could not be seen due to the occlusion of the ground by the interior of the vehicle. The view of the area directly to the rear of the vehicle is also limited for a distance of approximately 9.5m in that the lowest object could not be seen. Directly behind the vehicle...
for approximately 2.5m only the tallest test object could be seen (140cm). This is equivalent to the height of an average car.

In comparison, the restricted field of view plot for the 50th percentile male shows that although the driver is afforded a reasonable range of forward vision, there are significant blind spots caused by the vehicle A’ pillars (see Figure 31). In some squares, the volunteer was unable to see even the tallest object. These blind spots could hide a cyclist or motorcyclist at a junction. The restricted driver is unable to lean and tilt enough to see around this obstacle. In addition, although the view is wide, the volunteer admitted that areas seen in the extremes of their peripheral vision (i.e. in squares M, N, Q and R) were very ambiguous and unfocussed and it would be difficult to rely on this view in a real driving context.

To the rear, there is a greater limitation of vision than the unrestricted view in terms of both size of the limited area and the height of objects that can be seen. The red area to the rear of the vehicle extends all the way to the back of the grid (approximately 11m from the rear of the car) and demonstrates the impact of the headrest on the view of a restricted person. This limitation to the rear would cause significant problems during parking as drivers would be unable to see low objects such as bollards and children. The restricted driver has no view at all of the “blind spot” area and the areas further to the side of the vehicle.

These results confirm the findings of the user survey that people with restricted movement are likely to have problems with reversing and seeing objectives in the blind spots. They are also likely to have problems at some junctions depending on the angle of the junction. Those with acute angles that require the drivers to look beyond 90° (e.g. into squares M, N, G, H, Q, R, K, L) are likely to present most difficulty to drivers with restricted movement.

7.3.2 View provided by junction cameras

Figure 32 shows the left and right view provided by the junction cameras. The junction cameras provide a wide view to the sides of the vehicle which would cover quite a range of junction angles. The orange/red areas to the left and right of the vehicle bonnet show how the door mirrors obstruct the camera view of lower objects.

The crossed areas represent the area seen in the camera image of the door mirror (i.e. what the mirror reflects to the camera’s point of view). The medium sized object could be seen in this area (80cm). This is an interesting side effect of the camera position; the door mirror partially obscures the camera view but it also provides some additional vision further to the rear of the driver. The information from this source is likely to be very difficult to interpret in terms of position in relation to the vehicle.
Figure 30 50th percentile male height unrestricted vision
Figure 31 50th percentile male height restricted vision

1.45m object visible in standard mirrors
50cm object visible in standard mirrors
15cm object visible in standard mirrors
Figure 32 View provided by junction cameras
Figure 33 Combined junction camera and restricted view
Figure 33 shows the combined junction camera and 50th percentile male restricted view. The purpose of this diagram is to illustrate the all round vision that might be available to a restricted driver with junction cameras installed.

The combined diagram shows that the front view of the restricted driver and the junction camera view overlap so that the driver would have continuous vision for approximately 270° around their eye point. The majority of the areas of the junction camera view which are occluded by the door mirror are visible at the lowest level using normal vision. However, the blind spots caused by the vehicle A’ pillar are not compensated for by the junction camera.

On the right hand side of the vehicle the view provided in the camera image of the door mirror (i.e. the crossed area in Figure 33) meets the normal rear view of the restricted volunteer. The camera therefore, covers the vehicle blind spot as well as the junction view it was designed to provide. However, as previously discussed, this view is unlikely to be usable and objects below 80cm may not be visible.

On the left hand side, there is a significant gap between the limit of the view provided by the junction camera and the limit of the restricted volunteer’s rear view. However, the junction camera system was not designed as a blind spot viewing system and as long as users are aware of the intended use of the system and the limits of the view provided this should not present a problem.

Purely on the basis of the field of view measurements, the junction camera system appears to compensate for restricted movement quite well. The camera provides a view of the 15cm object in most of the junction relevant areas which are completely visible to the unrestricted driver but not the restricted driver (M, N, Q, R, G, H, K, L, A and F). According to the field of view measurements the system should provide a reasonable view even at junctions with acute angles. However, these results relate to the range of vision not the quality of vision and it should be taken into account that the target used for detection was conspicuous and presented in an expected location. Objects in the road environment would not have the same advantages.

**7.3.3 View provided by gooseneck mirror**

Figure 34 shows an example of the view that can be provided by a gooseneck mirror. The example is of a gooseneck mirror adjusted to provide a view to the right for use at junctions. The mirror can be adjusted to any angle and can be attached to any of the windows in the vehicle.

The gooseneck mirror provides a reasonable field of vision to the right of the vehicle which would cover a range of different junction types. However, the diagram shows that in this position the vehicle’s A pillar creates a very serious blind spot. In the area situated at 90° to the vehicle and approximately level with the vehicle bonnet only the medium and tallest objects can be seen. To the rear of this, in squares Q and R there is a large blind spot where none of the target objects can be seen. The convex surface of the mirror causes the blind spot to increase in size the further the distance from the vehicle. At a distance of approximately 15m from the side of the vehicle the blind spot, where none of the target objects could be seen, is almost 5m wide. A blind spot of this size could hide a car or even larger vehicle and it is in a critical position for making observations at junctions.
Figure 34 View provided by a gooseneck mirror
Figure 35 Restricted view (left) and combined gooseneck mirror and restricted view (right)
Figure 35 shows the gooseneck mirror view and the restricted view combined. This illustrates the view that a person with restricted movement using a gooseneck mirror for junction view may have to the right. To the front of the vehicle, in squares V, W and X, the gooseneck mirror offers no additional benefits over the restricted view. It offers some additional view in squares Q, R, K, L and F. The extra view provided would be helpful at some junctions with quite severe acute angles. However, the blind spot created by the A’ pillar would severely limit the use of the gooseneck mirror at junctions with less severe angles.

The combined gooseneck mirror and restricted view does not meet the standard of the unrestricted view. In the unrestricted view there were no blind spots on the right side of the vehicle and the lowest object could be seen in all squares to the right except for those closest to the vehicle.

### 7.3.4 Comparison of view provided by junction camera and gooseneck mirror

In terms of the angle of the vision cone provided by the gooseneck mirror and junction cameras, the gooseneck mirror provides a slightly wider range of vision overall. Both of the junction view devices suffer from a certain amount of obstruction from the vehicle itself. The junction camera view is obstructed by the door mirror so that the lowest object could not be seen in a small area to the side of the vehicle. However, this obstructed area could be seen completely in the restricted condition with no devices so did not result in a limited view overall. In most other areas of the junction camera view the lowest object could be seen. In contrast, the gooseneck mirror view is obstructed by the vehicle A’ pillar which creates a very large blind spot where none of the test objects can be seen.

The angles of vision provided by the two devices differ slightly. The view of the gooseneck mirror overlaps with the restricted front view more than the junction camera and provides less view towards the rear wings of the vehicle.

Overall, the junction camera system provided the best compensation for restricted movement of the two devices. The view provided covered more of the areas which could not be seen in the restricted condition and was more reliable in terms of being able to see the lowest test object. There were no significant blind spots. However, this conclusion is based on the field of vision provided by the camera and does not take into account the quality of the image or any other usability issues. The wide range of the gooseneck mirror may be useful for other applications, such as reversing, or in other vehicles where it can be positioned more effectively.

### 7.3.5 View provided by reversing camera

Figure 36 shows the rear view provided by the reversing camera. The reversing camera provides a wide view to the rear of the vehicle which would be very useful for reverse parking. The way in which there are very few orange areas and no red areas at all demonstrates that the camera not only provides a wide rear view, but also a view which would enable drivers to see low level objects.

The range of vision cone provided by the reversing camera gets wider the further away an obstacle is from the vehicle. At its narrowest point (closest to the vehicle) the range of vision provided by the camera spans approximately 0.5 metres at the widest point measured (approximately 11m from the rear of the vehicle), the view spans 15.5 metres. Figure 37 shows the combined reversing camera view with the 50th percentile male restricted view (the forward facing data points have been removed from this diagram as the reversing camera is concerned only with the rear view). The function of this diagram is to show the rear vision that might be available to a restricted driver if they had a reversing camera installed.
Figure 36 Rear view provided by the reversing camera
The combined diagram shows that the reversing cameras appear to improve the field of vision available to drivers with restricted neck and trunk movement. When combining the reversing camera view with the 50th percentile male restricted view, the vehicle features have not created a blind spot in the way that the vehicle’s A pillar did for the Gooseneck Mirror.

Purely on the basis of the field of view measurements, the reversing camera system seems to compensate for restricted neck and trunk movement very well. The camera provides a view of the lowest (15cm) object in most of the areas which would be relevant to a driver performing a reversing task. Blind spots created by the head rest, the rear of the car and the vehicle’s B and C pillars are eliminated through use of the reversing camera. This is thought to be because the camera is embedded into the rear bumper allowing the restricted driver to see the object when it would normally be obscured by the vehicle itself.

When the view provided by the reversing camera was combined with the 50th percentile male restricted view, many of the red and orange areas were replaced with green areas, indicating that the view provided by the reversing camera was better than the restricted view as the lowest object could be seen in more cases. This was particularly noticeable in squares C and D, where all of the orange and red areas were replaced with green areas. Also, all of the red and white areas were replaced with green areas in squares I and J.

The field of view measurement suggests that the reversing camera system adequately compensates for restricted neck and trunk movement for reversing tasks. Furthermore, the reversing camera appears to provide a better field of view to the rear of the vehicle than that of the unrestricted driver (see Figure 30). However it should be noted that, as with the junction camera system, the results relate to the range of vision provided by the reversing camera and not the quality of the vision. The fact that the target used for detection was conspicuous and presented in an expected location should also be taken into consideration when interpreting these findings.

7.3.6 Sensing range of reversing sensors (auditory and visual combined)

Figure 38 shows the sensory range provided by the reversing sensors (auditory and visual combined). This range at first appears to be somewhat limited; the sensors only detected the objects in parts of squares O, P, I and J. However, the system is designed to alert the driver to unseen objects close to the vehicle during low speed reversing manoeuvres. When compared to the restricted field of view plot, the reversing sensor can be seen to provide detection of much lower objects than can be seen by the driver. However, when the lowest object got too close to the vehicle, it appeared to be too low to be detected by the reversing sensors. It was questioned whether this could be problematic as the sensors may not detect a kerb but this should not cause any damage to a vehicle and may in fact be desirable in a parallel parking situation where the driver will need to be near the kerb.

Figure 39 shows the sensory range provided by the reversing sensors combined with the restricted view. While the sensors do not detect anything beyond squares I and J, the red areas in squares O and P are replaced with green and orange areas, demonstrating that the sensors provide detection of lower objects better than a driver with restricted neck or trunk function. Furthermore, areas to the side of the vehicle where in the restricted view not even the tallest of objects could be detected, the small and medium objects could be detected by the reversing sensors. It is therefore felt that reversing sensors have the potential to provide benefit to drivers with restricted neck or trunk movement in alerting the driver to unseen objects close the vehicle during low speed reversing manoeuvres.
Figure 38 Sensory range provided by reversing sensors
Figure 39 Sensory range provided by reversing sensors combined with restricted view
Figure 40 Rear view provided by the panoramic mirror for the 5th percentile female
Figure 41 Rear view provided by the panoramic mirror for the 50th percentile male
Figure 42 Rear view provided by the panoramic mirror for the 95\textsuperscript{th} percentile male
7.3.7 **View provided by panoramic mirror and viewpoint differences**

Figures 40, 41, and 42 show the rear view provided by the panoramic mirror for the three different height participants (when restricted). The view provided by the panoramic mirror varies between different height participants- there was little difference between the patterns produced for the 50th and 95th percentile males, but the pattern for the 5th percentile female was very different. This is likely to be because there was a small difference in height between these two participants and a large height difference between the 50th and 95th percentile males and the 5th percentile female.

On the right hand side, the ‘blind’ areas for the 50th and 95th percentile males were fairly similar; a small blind spot was created by the B pillar and a larger blind spot was created by the rear headrest; this blind spot spread out to approximately 4.25 metres at its widest point. For the 5th percentile female, there was only one blind spot, but it covered a much larger area than those created with the taller participants and spanned approximately 7.25 metres at its widest point. The trend in the view provided by the panoramic mirror seemed to be that the taller the observer, the more frequently the lowest object could be seen.

On the left hand side, once more, the 50th and 95th percentile males showed a very similar pattern to one another; with the 95th percentile male able to see a higher proportion of lowest level objects than the 50th percentile male. The size of the blind spots created by the B pillar on the left side was similar for all of the three heights (approximately 2.5 metres at the widest point). The second blind spot on the left hand side was much larger for the 5th percentile female (approximately 4.25 metres at the widest point) than it was for the 50th and 95th percentile males (where there was an average of approximately 2.5 metres) at the widest point.

The view to the rear using the panoramic mirror was very similar for all three heights when the panoramic mirror view was combined with the restricted view, this suggests that the panoramic mirror provided no extra view directly behind the car than the test vehicle’s standard rear view mirror.

It can also be seen that the panoramic mirror does not compensate fully for restricted neck or trunk movement. There are still three occluded areas; these correspond to the position of the headrest on the right hand side and the B pillars on both sides. It is thought that the panoramic mirror’s usefulness is very much dependent on the height of the driver. It provided a far better view for the 95th percentile male participant than it did for the 5th percentile female participant.

7.3.8 **Comparison of view/sensing range provided by reversing camera, reversing sensors and panoramic mirror**

In terms of the field of view provided by the reversing aids, the reversing camera provided the best overall rear view. The reversing sensors sensed only a very small area behind the vehicle. The sensors did however, sense the lower level objects closer to the vehicle than could be seen in the restricted and unrestricted views.

The panoramic mirror, like the junction view devices suffered a certain amount of obstruction from the vehicle itself (namely the B pillars and the headrest on the right hand side). The reversing camera was the only reversing aid which allowed the restricted driver to see the lowest object when it was positioned directly behind the vehicle.
Overall, the reversing camera system provided the best compensation for restricted movement of all of the reversing devices tested; it not only provided the largest best field of view, but it also gave a view to the rear of the vehicle which was better than that of an unrestricted driver because of where the camera was positioned. The usefulness of the panoramic mirror is thought to be very much dependent on the height of the driver; it provided a far better view for the 95th percentile male participant than it did for the 5th percentile female. The usefulness of the reversing sensors is dependent on the height of obstacles near the vehicle; where reversing occurs near low level objects, the sensors may not detect them; therefore the sensors may not be useful in certain parking situations.

7.3.9 View provided by blind spot mirror and viewpoint differences

Figures 43, 44 and 45, show the view afforded by the blind spot mirrors for the 5th percentile female and the 50th and 95th percentile male participants. For all three participants, the installation of blind spot mirrors served to extend the cone of vision available to the restricted driver; it also expanded the region in which the lowest object could be seen. Furthermore, for all three participants, the cone of vision extended beyond the edge of the grid (a width of over 30 metres).

It is thought that, because of the wide field of vision created, blind spot mirrors would be useful to drivers with restricted movement for lane change manoeuvres on dual carriageways and motorways. The blind spot mirrors seem to offer broad fields of vision at all three of the seating heights unlike the panoramic mirror, which seems to be very much dependent on seating height. Figure 46 shows this for the 50th percentile male stature participant.

7.4 Summary of main findings

- The junction camera provided a good view (i.e. down to 15cm from the ground) of most of the region that was not visible to the severely restricted driver.
- The gooseneck mirror provided a wide view which was slightly wider than the view provided by the junction camera. The gooseneck mirror therefore has potential to provide significant additional view. However, very large blind spots were created by the A pillars in the test vehicle.
- The reversing camera field of view measurements showed that the system provided a very good view directly behind the vehicle to show very low objects and for a good distance behind the vehicle. There would be a risk of striking objects at the rear corners close to the vehicle, although this risk is no greater when using the reversing camera than when using no aids.
- The detection range of the reversing sensors covers the area directly behind the vehicle up to a distance of approximately two metres. When compared to the restricted field of view plot, the reversing sensor detected much lower objects than could be seen by the restricted driver and therefore has the potential to provide benefit in the way it was designed.
- Although the panoramic mirror provided a wide view there were significant blind spots and low objects could not be seen. The view directly to the rear of the vehicle was no different to that provided by a standard rear view mirror. The effectiveness of the mirror was also affected by the driver’s seating position. Those drivers with a lower position could see far less than taller people. As such, although the device may be useful for providing enhanced general awareness of traffic around the vehicle, it is unlikely to be useful for reversing tasks where vision of low objects is most beneficial.
Figure 43 View afforded by the blind spot mirrors for the 5th percentile female
Figure 44 View afforded by the blind spot mirrors for the 50th percentile male
Figure 45 View afforded by the blind spot mirrors for the 95th percentile male
Figure 46 Combined restricted and blind spot mirror view for the 50th percentile male
8 Phase 4a: Inspection of safety of installation

8.1 Background
The majority of cars in the UK are designed to meet European safety legislation and the retrofitting of some features could potentially create a conflict with the standard safety design. An example of such a safety conflict is where steering wheel mounted controls are installed to aid a driver. Such a modification may require the steering wheel airbag to be deactivated. An assessment then needs to be undertaken to evaluate the benefits of the additional device versus the potential harm that could be caused to a driver in a moderate or more severe frontal collision. It is common for airbags and seatbelts on modern vehicles to be designed to work together, so the deactivation of an airbag may also require the seatbelt on the vehicle to be changed too.

8.2 Aim
The aim of this phase was to assess the installation of each device in terms of risks posed to the driver or others by the presence of the device in/on the vehicle.

8.3 Method

8.3.1 General approach
Skilled vehicle safety experts, with in-depth knowledge of both crash and injury mechanism causation factors, assessed if any disadvantages were associated with the observational devices which were fitted to the test vehicle related to the occupants of the car and other road users. The evaluation considered if the additional features could:
- Potentially contribute to the cause of a crash (primary); or
- Increase the likelihood and severity of injury should a collision occur (secondary).

8.3.2 Accident risk versus injury severity
Each observational device was assessed to determine if they would pose any additional risks to the car driver or others, initially as a cursory review with respect to routine daily use of the vehicle, followed by a more in-depth investigation of the implications should a collision occur. There is a balance required when judging any potential for increased harm should a crash occur against the likelihood of the accident if the device was not fitted.

The user survey found that some drivers adapt their behaviour and sitting position and/or driving style to compensate for restricted neck/trunk movement. Therefore, it is difficult to generalise as to the relative risk associated with a device, given the variation in the practices of the users. A good device could improve a driver’s control of his car and change his sitting position, but may present a different risk should a crash occur. However, there is a balance between an effective device which reduces the risk of a collision versus the risk it poses if struck by an occupant or another road user.

8.4 Results

8.4.1 Primary safety
None of the devices were judged to present additional risks during general use of the vehicle compared with the standard fixtures and fittings. Although none of the devices were thought
to interfere with the physical operation of the car, aspects which were also highlighted in the ergonomic review were uncovered, including the following:

- As the two-way mirror display is darker than a standard rear view mirror, it may make it more difficult to see pedestrians walking close to the rear of the car.
- Because the panoramic mirror has such a large reflective surface, it is likely to generate more headlight glare than a standard mirror.
- The most important effect that the gooseneck mirrors could have is obscuring the vision of the road in front of the driver as well as increasing the blind spot caused by the A-pillar. Another possible problem relates to the view they provide out of the side windows which is distorted.

8.4.2 Secondary safety

8.4.2.1 Compensation strategies

In the user survey, some of the compensation strategies that were mentioned were of concern to the vehicle safety experts. One strategy of taking off a seat belt is likely to have a huge impact on the injuries suffered in most types of crash. Occupants who are not restrained are in danger of contacting more points of the interior with higher severity than they would if a seatbelt was used.

Removing the seat belt cannot be recommended in any circumstances except for low speed reversing where it is permitted and may be beneficial. Another strategy which was of concern was sitting sideways in the seat in order to obtain a better view. This potentially reduces the effectiveness of the seat belt and the other restraint features. Depending on the individual and the amount of rotation within the seat, this could also restrict the driver’s ability to fully control the vehicle.

8.4.2.2 Junction camera

Due to their position on the lower A-pillars on both the near and the offside, the junction cameras pose a number of potential problems. The most obvious possible effect on safety is the injury they would cause if contacted by an occupant. In a frontal impact, a side impact or a rollover the front row occupants could strike the A-pillars, and the presence of these cameras can only increase the severity of any injury they sustain. The test vehicle was not fitted with a curtain or cant rail mounted airbag. It is likely that in their current position the cameras would effect the operation of such an airbag, and so would need to be moved to a more suitable position, possibly connected to the door rather than the A-pillar.

8.4.2.3 Panoramic mirror

As the panoramic mirror is much larger than a standard mirror, the likelihood of an occupant striking it in a frontal impact, side impact or a rollover is increased. It is made of lightweight reflective plastic, so the possibility of suffering serious lacerations from striking the mirror is small. Although it is connected to the existing mirror with a metal bracket, it is probably the strength of the original mirror that would determine any injury suffered from striking this part.

8.4.2.4 Reversing sensors

The reverse sensor display is very small and located in a position which is unlikely to be contacted by an occupant. Possible situations where it could play a part in injury would
involve a rear impact by a large vehicle or an impact where an occupant is thrown backwards relative to the car’s forward movement. In both these situations injuries are likely to be severe whether the reverse sensor display is present or not.

The reversing sensors themselves are located on the rear bumper of the vehicle without protruding from the bodywork; it is very unlikely that they would have any additional effect if a pedestrian or other vehicle was struck.

8.4.2.5 Reversing camera

As the reversing camera itself is situated just below the number plate on the rear of the car and does not protrude far from the bodywork, and is very unlikely to have any additional effect when striking a pedestrian or another vehicle.

8.4.2.6 Blind spot mirrors

Located on the door mirrors, these offer no additional danger to any occupants or pedestrians.

8.4.2.7 Gooseneck mirrors

Contact with the gooseneck mirrors is unlikely to cause any serious injury other than bruising or minor lacerations, as they would detach from the windscreen under impact.

8.4.2.8 Display screen for junction and reversing camera systems

Although the display screen for the junction and reversing cameras on the two-way mirror is larger and wider than the normal rear view mirror, it would not pose a much greater risk of injury if struck by an occupant as it is made of similar material and does not have any sharp edges.

8.5 Summary of main findings

In summary, no major primary safety problems were identified with any of the devices, with the possible exception of the gooseneck mirrors. They were found to be in the line of vision forwards and could increase the blind spot associated with the A-pillar.

In terms of secondary safety, the junction camera produced most concern as its position on the A-pillar means that the injury severity would be greater on impact and could possibly interfere with the deployment of an airbag in some vehicles. It was felt to be more likely that in the event of a frontal or side impact or rollover that an occupant would come into contact with the panoramic mirror or two-way mirror (display for the junction and reversing cameras) due to their size relative to the standard rear view mirror. However, the injury severity would not be increased.

The reversing sensor visual display system was considered to be in a position unlikely to be contacted by a car occupant. The reversing sensors, reversing camera, and blind spot mirrors were also considered to pose no additional risk to pedestrians or other vehicles. It was thought that in the event of a collision, the gooseneck mirrors would detach from the windscreen and not cause a serious injury.
9 Phase 4b: User testing

9.1 Aims

- To assess the extent to which the devices have the potential to compensate for restricted neck and trunk movement.
- To observe non-disabled and disabled users to see what usability problems are encountered.
- To collect user comments on the usability and desirability of each system.

9.2 Method

9.2.1 General approach

In order to evaluate each device objectively, a repeated measures (within subjects) experimental design was used. The design had three counter-balanced conditions for 10 non-impaired participants who were all current licensed drivers:

1. **Unrestricted**: Non-impaired participants performed tasks using normal vehicle mirrors only. This provided a benchmark for “safe” performance as it was assumed that the performance of licensed drivers who have no impairment is acceptable.

2. **Restricted**: Non-impaired participants were artificially restricted and performed the same tasks using normal vehicle mirrors only. This condition quantified the level of impairment that may be experienced by people with restricted neck/trunk movement and provided a benchmark against which to compare any improvements provided by the devices.

3. **Restricted with devices**: Non-impaired participants were artificially restricted and performed tasks with the assistance of each of the observation devices. This condition quantified the benefit of each device and was compared to the safe level benchmark to assess whether the device had the potential to compensate for impairment to a safe level.

This design had the advantage of providing a highly controlled evaluation. However, it had the disadvantage of not including the perspective of people who have restricted neck/trunk movement. It was considered important to include real potential users in the evaluation for several reasons:

1. People with restricted neck/trunk movement may need to rely totally on the device and as such may have a different point of view regarding usability, confidence and desirability of the device.

2. People with restricted neck/trunk movement often experience other associated difficulties, such as pain and discomfort, and may have other disabilities which may affect their ability to use the device.

Therefore, a validation phase with four impaired current drivers was also carried out. The same tasks were repeated in a **restricted without devices** condition (i.e. how the participant would normally drive), and a **restricted with devices** condition (i.e. the assistance of the devices in turn). This phase was added in order to validate the findings of the experimental
evaluation with impaired drivers as well as to collect their unique perspective and explore additional issues which may affect their ability to use the device effectively.

9.2.2 Participants

The experimental evaluation was conducted using 10 non-impaired participants recruited from the TRL database. The four disabled participants for the validation phase were recruited from the user survey sample. All participants had good or corrected vision equivalent to the distance acuity level of 6/10 on a Snellen chart.

Six of the ten participants in the main trials were female and four were male. Their ages ranged from 21 to 68 with a mean age of 47.5 years. This is compared to the four participants in the validation phase, three of whom were female and one male, and their ages ranged from 52 to 71 (mean 60.5 years).

The mean number of years driving experience for the main participants was 28.8 (range 3-48) compared to 28.3 (range 21-40) for the validation participants. The mean annual mileage for the two groups was similar, with a mean of 7,350 (range 10,000-12,000) for the main and 6,500 (range 4,000-10,000) for the validation. The type of driving that the participants did was also similar for both groups, with those in the validation phase having a slightly higher proportion of urban driving (60% compared to 53.5% respectively), similar proportion of rural driving (23.8% compared to 22.4%), and less motorway driving (16.3% compared to 24.1%).

None of those in the validation phase were employed at the time of the project. One of the main phase participants drove regularly for work, two occasionally drove for work, whilst the remaining seven were not required to drive for work. None of the participants drove a Ford Focus (the same as the test vehicle). All those in the main phase drove a vehicle with manual transmission compared to one of the validation phase participants (three drove an automatic transmission vehicle). Five of the ten participants in the main phase were licensed to ride a motorcycle (compared to one in the validation phase), three were also licensed to drive a light goods vehicle (compared to one in the validation phase), one could also drive a large goods vehicle (compared to one in the validation phase), but none could drive a PSV/bus (compared to one in the validation phase).

None of the participants had previously used a junction camera, visual reversing sensor, or reversing camera. Three of the validation phase participants had previously used a panoramic mirror (compared to none in the main phase), three had used blind spot mirrors (compared to two in the main phase), and one had used a gooseneck mirror (compared to none in the main phase). Two of the participants in the main phase had also used audible reversing sensors.

The levels of experience with certain driving manoeuvres did not differ greatly between the main and validation phase participants, with the exception of the three-point turn which the validation participants reported having less experience carrying out (from the user survey this could be seen to be due to using avoidance tactics as a compensation measure). The main phase participants reported having more confidence than the validation participants when performing each of the manoeuvres. This can be seen in Table 6.
Table 6 Self reported experience and confidence in driving manoeuvres (mean values)

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<td>Junctions</td>
<td>5.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Reverse parking</td>
<td>4.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Three-point turns</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Changing lanes</td>
<td>4.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

None of the ten participants in the main phase reported a medical condition which may have affected their driving. The four participants in the validation phase reported the following conditions with subsequent restriction of movement and affect on their driving.

1. Ehlor Danlos Syndrome type 3 and permanent tendonitis in all joints with pain being the main problem when driving.
2. T1-T4 broken which resulted in weakness in arms, hands, and loss of feeling in legs and feet.
3. Paraplegia which restricts trunk movement, paralysed from the waist down.
4. Rheumatoid Arthritis and Osteo Arthritis and unable to move head to turn right or left due to pain caused and restricted up and down movement due to a tear which cannot be operated on and minimal use of left arm.

9.2.3 Procedure

A set of tasks/exercises were devised to assess each of the seven devices as shown in Table 7. The Small Road System (SRS) of the TRL test track was used to be able to test the capabilities of the devices in a controlled road environment without other (unpredictable) road users and thereby ensuring the safety of participants, researchers, and public road users. A map of the SRS and the locations for each of the driving tasks can be seen in Appendix F.
Table 7 Set of tasks to assess each device

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Driving tasks</th>
<th>Applicable devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junctions</td>
<td>Distance detection left and right:</td>
<td>Junction cameras</td>
</tr>
<tr>
<td></td>
<td>• Car</td>
<td>Gooseneck mirrors</td>
</tr>
<tr>
<td></td>
<td>• Cyclist</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Usability test looking at decision-making</td>
<td></td>
</tr>
<tr>
<td></td>
<td>confidence</td>
<td></td>
</tr>
<tr>
<td>Reversing</td>
<td>Reverse parking</td>
<td>Auditory reversing sensor</td>
</tr>
<tr>
<td></td>
<td>Turn in the road</td>
<td>Visual reversing sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reversing camera</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panoramic mirror</td>
</tr>
<tr>
<td>Lane change</td>
<td>Lane change</td>
<td>Blind spot mirror</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panoramic mirror</td>
</tr>
</tbody>
</table>

The order of the driving tasks was the same for each participant and was specifically:
1. Reverse parking
2. Lane change
3. Turn in the road
4. Junction detection (acute angled\(^{13}\) and right angled\(^{14}\))
5. Junction usability

Prior to the driving tasks, the researcher gave a demonstration of the vehicle, SRS and devices. To further this familiarisation session, the participant was then given specific standardised instructions to ensure that all the manoeuvres had been performed and devices used and were then given an opportunity to drive around the SRS as a ‘free time’ of up to 10 minutes.

Up to three researchers were used for the trials at any one time, and are referred to here as R1, R2 and R3. They communicated using a two-way radio. The instructions given by researcher to participant are Appendix G and permutations for each of the driving tasks given in Appendix H.

As for the Phase 4a range of vision/detection, the vehicle used was a Ford Focus. A second stimulus vehicle was also hired for use during certain tasks, namely the turn in the road, lane change, and junction detection. It was ensured that this vehicle was always a white Ford Focus estate so that the make, model and colour were consistent throughout the trials. A bike was also used as a stimulus vehicle.

9.2.3.1 Reverse parking

Both reversing tasks (reverse park and turn in the road) needed to be conducted dynamically in order to properly assess the devices as one of the key features was the interpretation of the feedback provided by the device. For the reverse parking, R1 accompanied the participant in the vehicle, gave instructions and collected subjective measures. R2 was responsible for collecting objective measures. Parking spaces were delineated by white parking space lines

\(^{13}\) 155° angle to the right (25° to the left).

\(^{14}\) 90° angle to the right and left.
and orange traffic cones such that no damage would be caused to the vehicle or occupants if struck at slow speeds.

![Figure 47 Reverse parking](image)

The participant was instructed to park the test vehicle at a specified marked starting point and then to carry out a reverse park manoeuvre into a specified space before returning the vehicle to the starting point once more. This can be seen in Figure 47. They were asked to repeat this for each of the conditions detailed below.

At the end of the manoeuvre for each condition, R1 asked the participant the following subjective questions:

1. How easy or difficult was it to reverse into the space?
2. How confident or unconfident did you feel reversing into the space?
3. How good or bad was the view given by this observation method?
4. What problems did you find using this reversing aid?
5. What benefits did you find using this reversing aid?
6. Observation of usability issues (R1)

R2 took the following objective measurements:

1. Total time taken to complete the task from starting to move to sounding horn
2. Number of “Critical exceedances” – times that any part of the vehicle crosses the lines delineating the parking space.
3. Photo of parking – For some kind of later judgement of parking quality

### 9.2.3.2 Blind spot

For this driving task, R1 instructed the participant to park the test vehicle on the left hand side of the road alongside the kerb at a marked location. R2 then used the stimulus car to drive at, firstly, 10mph and, secondly, 30mph in the other lane of the SRS, as if overtaking. This was repeated in all conditions, which were counter-balanced across participants.

R1 took the following subjective ratings after the stimulus car had past in each permutation:
1. How good or poor was your view of the vehicle approaching from behind?
2. How clearly or unclearly could you see the vehicle approaching from behind?
3. How easy or difficult was it to judge the speed of the vehicle approaching from behind?
4. How easy or difficult was it to judge the position of the vehicle approaching from behind?
5. How confident or unconfident would you feel making a lane change using this observation method?
6. How confident or unconfident would you feel making a lane change using this observation method?
7. How helpful or unhelpful was the observation aid?
8. What problems were there using this observation aid?
9. What benefits were there using this observation aid?

9.2.3.3  Turn in the road

For this driving task, participants were asked to park the vehicle at a specified marked starting point and then to carry out a turn in the road whilst saying “now” when they see a flash from the headlights of another stationary vehicle (operated by R2) and/or the torch from a stationary person simulating a pedestrian or cyclist (operated by R3). They were asked to bring the vehicle to a halt at a specified marked finishing point and repeat this for each condition, the order of which was counter-balanced across participants. They were given a practice before each.

A pattern of flashing was calculated so that R2 and R3 were consistent in their approach for each participant and condition. This consisted of the researcher in the stationary car flashing the headlights once, then the researcher with the torch waiting three seconds before turning it on and off (at chest height). The researcher in the stationary car would then wait a further three seconds before flashing the headlights once again. This would continue until the participant and the test vehicle had come to a halt at the finishing point.

R1 noted observations of usability issues and counted the number of times the participant said “now”. At the end of every manoeuvre, they also asked the participant the following subjective questions:

1. How easy or difficult was it to complete the turn in the road?
2. How confident or unconfident did you feel turning in the road?
3. How helpful or unhelpful was this reversing aid?
4. What problems did you find using this reversing aid?
5. What benefits did you find using this reversing aid?

R2 was responsible for taking the following objective measurements:

1. Total time taken to complete the task from starting to move to stopping at the finish marker
2. Number of “Critical exceedances” – times that any part of the vehicle contacts or mounts the kerb
3. Number of “Points”, i.e. the number of turns that the participant makes during manoeuvre from start to finish.

9.2.3.4 Detection at Junctions

Detection of a car and, secondly, a bike (specified to the participant) was tested at two junctions. The location for the test vehicle at each junction was marked out and positioned by the researcher to ensure it was the same for each participant.

The intersection of the first junction (see Figure 48 and Appendix F for location) with the main road presented the participant with a 155° angle to the right. The user testing pilot trials showed there was little difference between the view afforded to the right and left with the vehicle positioned as if turning right or left and so it was decided to test this in the right position only.

![Figure 48 Junction detection task at 155° angle to right](image)

The intersection of the second junction (see Figure 49 and Appendix F for location) with the main road was approximately 90°. The test vehicle was positioned in the centre of the lane.

![Figure 49 Junction detection task at 90° angle to right and left](image)

R2 approached the junction from the right, firstly in the stimulus car and then on the stimulus bike (wearing a high visibility vest for safety) when R1 indicated that they were ready. R2
stopped the stimulus vehicle upon hearing the test vehicle’s horn and then measured and recorded the distance from the centre point of the junction along the side of the road edge using a trundle wheel. From this, the decision time available for traffic at different speeds was calculated. See Figure 50 for how this was measured.

Meanwhile, R1 carried out the subjective questionnaire with the participant and gave instructions for the next permutation/condition. The subjective measures included:

1. How easy or difficult was it to detect the on-coming vehicle?
2. How well could you see the on-coming vehicle?
3. How confident or unconfident would you feel pulling out at this junction using this observation method?
4. How safe or unsafe would you feel pulling out at this junction using this observation method?

This procedure was then repeated from the left direction and in each condition. The following remained constant:

- Order of junctions was always the acute and then right-angled junction
- For the right angled junction, the order of direction of approach was always left and then right (for the acute angled junction there was only one direction, i.e. right)
- Order of stimulus was always car and then bike
9.2.3.5  Junction Usability

R1 instructed the participant to stop at a specified marked position before the junction. They then carried out the junction manoeuvre left and stopped at another specified marked position. This was repeated for turning right and then for each condition. When all of the manoeuvres had been completed at the right-angled junction, all manoeuvres were repeated at the acute-angled junction.

For each manoeuvre, R2 measured time taken from start to finish and RI asked the participant the following subjective questions:

1. How easy or difficult was it to ensure that it was clear?
2. How confident or unconfident did you feel using this observation method?
3. How good or bad was the view given by this observation method?
4. What problems did you find using the observation method?
5. What was good about this observation method?

9.3  Analysis method

There were two groups of participants: artificially restricted and validation. The artificially restricted participants were the primary group of interest and their results were analysed separately from the validation participants. Analysis was conducted by testing for significant differences between pairs of conditions on each measure separately using the Friedman test. Subsequently, the validation participants’ results were analysed and compared to the artificially restricted participants’ results. This analysis was both within conditions (to look for differences between the two groups within the equivalent conditions) and between conditions (to see whether the pattern of differences between conditions was similar or different between the two groups). Within conditions comparisons were conducted using the Mann-Whitney U test and the between conditions analyses for the validation participants used the Friedman test.

9.4  Results

9.4.1  Junction detection

9.4.1.1  Conditions and measures

Four conditions were examined during the junction detection task:

1. **Unrestricted (Unr)** – With no restriction and no observation aids (artificially restricted participant group only)

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15 The Friedman test is a non-parametric statistical test. Similar to the parametric repeated measures ANOVA, it is used to detect differences in treatments across multiple test attempts. The procedure involves ranking each row (or block) together, then considering the values of ranks by columns.

16 The Mann-Whitney U test is a non-parametric test for assessing whether two samples of observations come from the same distribution.
2. **Restricted/Without devices (R)** – Artificially restricted participants wore the neck brace and validation participants drove as they normally would. No observation aids were used.

3. **Junction camera (JC)** – Restricted (artificially or genuinely) but were aided by the junction camera

4. **Gooseneck mirror (GM)** - Restricted (artificially or genuinely) but were aided by the gooseneck mirrors

The junction detection task collected four different measures:

1. **Detection distance** – the distance of the on-coming vehicle from the junction when it was first detected by the participant

2. **Ease of detection** – a subjective rating made by the participant on a 10-point scale in response to the question: “How easy or difficult was it to detect the on-coming vehicle?”

3. **Clarity of view** - a subjective rating made by the participant on a 10-point scale in response to the question: “How clearly could you see and recognise the on-coming vehicle?”

4. **Confidence** - a subjective rating made by the participant on a 10-point scale in response to the question: “How confident or unconfident would you feel pulling out at this junction using this observation method?”

Full analysis of each measure for each permutation of the junction detection test is reported in Appendix I. The key findings of the analysis are described in the following sections.

**9.4.1.2 Detection distance**

Table 8 shows the mean and standard deviation of the detection distance for each permutation of the test individually. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if there was an improvement (i.e. a longer detection distance) compared to the restricted condition and coloured red if there was a reduction in detection distance (i.e. if performance was worse) compared to the restricted condition. The measures are coloured blue if the difference between the restricted condition and the device condition was less than one metre. Figures shown in brackets below the means indicate the magnitude of the difference between the device conditions and the restricted condition.

The table shows that the observation aids provided an improved detection distance in most cases, although there were permutations where this was not the case, or where the magnitude of the improvement is quite small.
Table 8 Mean detection distance for all permutations, artificially restricted participant group

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean detection distance (m)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>91.45</td>
<td>49.09</td>
<td>58.07</td>
<td>61.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(+8.98)</td>
<td>(+12.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>8.07</td>
<td>13.43</td>
<td>17.53</td>
<td>22.41</td>
</tr>
<tr>
<td>Car, left approach</td>
<td>Mean</td>
<td>90.52</td>
<td>71.25</td>
<td>75.05</td>
<td>66.42</td>
</tr>
<tr>
<td></td>
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<td>(+3.8)</td>
<td>(-4.83)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>14.52</td>
<td>16.25</td>
<td>9.96</td>
<td>16.16</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>80.81</td>
<td>37.75</td>
<td>45.07</td>
<td>44.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(+7.32)</td>
<td>(+6.55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>10.81</td>
<td>24.05</td>
<td>18.23</td>
<td>19.86</td>
</tr>
<tr>
<td>Bike, left approach</td>
<td>Mean</td>
<td>90.90</td>
<td>67.52</td>
<td>67.86</td>
<td>58.72</td>
</tr>
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<td>(-8.80)</td>
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<td></td>
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<tr>
<td></td>
<td>S.D.</td>
<td>13.32</td>
<td>18.91</td>
<td>16.09</td>
<td>27.21</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>88.42</td>
<td>56.40</td>
<td>61.51</td>
<td>57.73</td>
</tr>
<tr>
<td></td>
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<td>(-1.33)</td>
<td></td>
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<tr>
<td></td>
<td>S.D.</td>
<td>9.87</td>
<td>15.98</td>
<td>13.37</td>
<td>19.57</td>
</tr>
<tr>
<td>Acute angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>164.18</td>
<td>12.58</td>
<td>105.31</td>
<td>124.03</td>
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<td>(+111.45)</td>
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<tr>
<td></td>
<td>S.D.</td>
<td>3.26</td>
<td>6.45</td>
<td>40.65</td>
<td>42.27</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>163.25</td>
<td>8.56</td>
<td>48.07</td>
<td>48.65</td>
</tr>
<tr>
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<td>(+40.09)</td>
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<tr>
<td></td>
<td>S.D.</td>
<td>2.28</td>
<td>4.17</td>
<td>16.85</td>
<td>23.97</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>163.72</td>
<td>10.57</td>
<td>76.69</td>
<td>86.34</td>
</tr>
<tr>
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<td>(+75.77)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.60</td>
<td>5.28</td>
<td>25.69</td>
<td>25.69</td>
</tr>
<tr>
<td>Both junctions combined</td>
<td>Mean</td>
<td>113.52</td>
<td>41.13</td>
<td>66.57</td>
<td>67.27</td>
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<td>(+26.14)</td>
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<tr>
<td></td>
<td>S.D.</td>
<td>7.19</td>
<td>10.69</td>
<td>13.31</td>
<td>18.72</td>
</tr>
</tbody>
</table>

The pattern of results was found to be quite different according to which junction the task was conducted at. Therefore, the results for the 90° angle junction and the acute angle junction are discussed separately.

Figure 51 shows the mean detection distance for both artificially restricted and validation participants. Detection distance in the artificially restricted group was significantly higher in the unrestricted condition compared to all other conditions. However, the detection distance
in the restricted condition was still reasonably large. The statistical tests showed no significant benefit of either of the observation aids in comparison to the restricted/without devices condition at this junction.

The detection distance of validation participants in the without devices condition was significantly higher than that of the artificially restricted participants in the restricted condition. This suggests that the limitation imposed by the artificial restriction was more severe than the limitation experienced by the volunteers with genuine restricted movement.

The pattern of results differed between the two groups, there were no significant differences between the restricted and device conditions in the artificially restricted participant group but in the validation group, the gooseneck mirror condition resulted in significantly lower detection distances than both the without devices and junction camera conditions. Figure 52 shows the mean detection distances for both groups of participants at the acute angle junction.
Figure 52 Mean detection distances (m) for artificially restricted and validation participants, acute angle junction all permutations combined

In the artificially restricted participant group, the distance achieved in the unrestricted condition significantly exceeded all other conditions. The detection distance in the restricted/without devices condition was very low in the artificially restricted sample. Both of the observation aids produced a significant improvement compared to this. However, they were still significantly lower than the detection distance in the unrestricted condition.

As before, the validation participants’ could see significantly further in the restricted/without devices condition than the artificially restricted participants and the results were much more variable. This supports the assumption that people with restricted neck/trunk movement vary greatly in their ability to turn and look, particularly at an acute angle junction. The coping strategies used to maximise observation ability while driving were permitted during the trial and this would have contributed to the variability of the results.

The significant benefit of the devices observed in the artificially restricted group was not observed in the validation group. This is likely because the level of limitation experienced by the validation participants in the without devices condition was not that severe in terms of task performance. However, this particular measure does not take into account the pain, discomfort or effort that may be required to achieve such detection distances at this type of junction.
9.4.1.3  

*Ease of detection ratings*

Participant ratings of ease of detection are of interest because the detection distance alone does not take into account factors such as physical effort and discomfort. People with restricted movement may achieve a good detection distance at the expense of pain, discomfort or fatigue. The pattern of ease of detection ratings in each condition was broadly consistent with the detection distances achieved by each group of participants.

The horizontal line in the following figures represents the median value (middle value). The upper and lower extremities of the box are the first quartile and third quartile values (i.e. 50% of the data lie within this range). The ends of the "whiskers" show the lowest and highest value.

![Box plot of ease of detection ratings](image_url)

**Figure 53** Rating of ease of detection, artificially restricted and validation participants, 90° angle junction
Figure 54 Rating of ease of detection, artificially restricted and validation participants, acute angle junction

In all cases, artificially restricted participants rated the unrestricted condition very positively and significantly higher than all other conditions.

At the 90° angle junction, artificially restricted participants’ ratings of ease of detection in the restricted/without devices condition were near to the mid point of the scale which indicates that even though it was rated significantly lower than the unrestricted condition it was still not thought to be particularly difficult. Artificially restricted participants rated the observation aids marginally higher than the restricted/without devices condition at the 90° angle junction. This difference was only significant for restricted vs. gooseneck mirror.

In contrast, at the acute angle junction, participants gave very low ratings for ease of detection in the restricted/without devices condition. Both observation aids were rated significantly more highly than the restricted condition.

At the 90° angle junction, the validation participants gave quite positive ratings in the restricted/without devices condition and participants saw no significant benefit of the devices. In fact, the gooseneck mirror was rated significantly lower than both the restricted/without devices and the junction camera conditions.

At the acute angle junction, validation participants gave lower ratings in the without devices condition compared to the 90° angle junction. This supports the assumption that this type of junction would present difficulty to people with restricted movement. The devices were not rated as significantly easier than the restricted/without devices condition according to validation participants.
9.4.1.4 Clarity of view ratings

Clarity of view ratings are of interest as they examine how easily objects could be recognised rather than how well they could be detected. An object may be detected because it moves or differs slightly from the background but this does not mean that the information is useful as the driver needs to see other traffic clearly in order to make judgements on direction, speed and likely behaviour.

![Subjective ratings of clarity, artificially restricted and validation participants, all permutations](image)

**Figure 55** Subjective ratings of clarity, artificially restricted and validation participants, all permutations

Figure 55 shows the mean clarity ratings for artificially restricted participants for all test permutations combined. Ratings in the unrestricted condition were significantly higher than all other conditions in all cases. Ratings in the unrestricted condition are very high but the maximum rating was not generally given due to obscuration by foliage and fencing on the track.

The mean rating for the restricted/without devices condition was on the lower side of the scale. This is probably because the participants would have been relying on peripheral vision, which is specialised to detect movement and does not provide good visual discrimination, to get the earliest view. The ratings given for the two observation aids were not significantly different from the restricted/without devices condition, even at the acute angle junction where an improved detection distance was provided.

Validation participants gave significantly higher ratings of clarity than the artificially restricted participants in the restricted/without devices condition at both junctions. They tended to have some movement and were therefore able to turn to some extent and look directly at the on-coming vehicles. At the 90° angle junction the validation participants gave
more positive ratings to the junction camera than the artificially restricted participants and also rated it significantly higher than the gooseneck mirror.

9.4.1.5 Confidence ratings
Patterns of confidence ratings were consistent with the detection distance and ease of detection results. As expected, artificially restricted participants gave significantly higher ratings of confidence in the unrestricted condition compared to all other conditions for all permutations of the test.

At the 90° angle junction, the observation aids did not significantly increase ratings of confidence among artificially restricted or validation participants compared to the restricted/without devices. Validation participants again showed a preference for the junction camera over the gooseneck mirrors and this difference approached significance.

At the acute angle junction, artificially restricted participants were significantly more confident using the observation aids compared to the without devices condition. However, levels of confidence did not equal those of the unrestricted condition. Validation participants’ ratings of confidence were quite positive in the without devices condition despite the acute angle and there were no differences between the device and without device conditions.

9.4.1.6 Junction detection summary of results
- The unrestricted condition (artificially restricted participants only) was significantly better than all other conditions at all permutations and for all measures.
- Validation participants were generally less restricted than the simulated restriction. Therefore, conclusions from the artificially restricted participant group can be said to apply to only the most severe cases of restricted movement.
- The junction camera and gooseneck mirror offered some benefit over severe restriction in terms of detection distance, ease of detection and driver confidence and was most effective at the acute angle junction. However, it did not compensate to the unrestricted level in any respect.
- The clarity of the view provided by the junction camera and gooseneck mirror was not rated very highly.
- There were generally very few statistically significant differences between the junction camera and the gooseneck mirror within the artificially restricted participant results. However, the validation participants showed a preference for the junction camera on some measures.

9.4.2 Junction usability

9.4.2.1 Conditions and measures
The junction usability test included all the same measures and conditions as the junction detection test. It collected four numerical measures:

1. **Time taken** – the time taken to approach the junction from the designated starting point, check that it was clear, make the turn and pull up at the designated end point
2. **Ease of checking** – a subjective rating made by the participants on a 10-point scale in response to the question: “How easy or difficult was it to ensure that it was clear?”
3. **Confidence** – a subjective rating made by the participants on a 10-point scale in response to the question: “*How confident or unconfident did you feel using this observation method?*”

4. **Quality of view** – a subjective rating made by the participants on a 10-point scale in response to the question: “*How good or bad was the view given by this observation method?*”

There is obvious overlap between the subjective ratings collected in the junction usability test and those given in the junction detection test. These measures were collected in order to determine participant opinion of both static and dynamic use of the systems. Qualitative data in the form of participant free comments and research observation of user difficulties, errors and behaviour was also collected and is discussed at the end of this section.

### 9.4.2.2 Time taken

Table 9 shows the mean and standard deviation of the time taken to make turns under the various observation conditions. Means were calculated across all artificially restricted participants and for each permutation of the junction usability test. Figures shown in brackets indicate the magnitude and direction of the difference between the device conditions and the restricted condition. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded:

- Green if there was an improvement (i.e. a faster turn time) compared to the restricted condition
- Red if there was a reduction in the time (i.e. if performance was worse) compared to the restricted condition
- Blue if the difference between the restricted condition and the device condition was less than one second.
### Table 9 Mean time taken to make turn, artificially restricted participants

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean time (s) 2 d.p.</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unr</td>
<td>R</td>
<td>JC</td>
<td>GM</td>
</tr>
<tr>
<td>90° angle junction Right turn</td>
<td>Mean</td>
<td>18.55</td>
<td>24.60</td>
<td>25.98</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.16</td>
<td>8.46</td>
<td>3.96</td>
</tr>
<tr>
<td></td>
<td>Left turn</td>
<td>Mean</td>
<td>18.68</td>
<td>29.76</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.54</td>
<td>11.17</td>
<td>12.37</td>
</tr>
<tr>
<td></td>
<td>Both combined</td>
<td>Mean</td>
<td>18.62</td>
<td>27.18</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.28</td>
<td>9.65</td>
<td>5.93</td>
</tr>
<tr>
<td>Acute angle junction Right turn</td>
<td>Mean</td>
<td>19.59</td>
<td>25.86</td>
<td>36.83</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>3.35</td>
<td>10.73</td>
<td>9.35</td>
</tr>
<tr>
<td></td>
<td>Left turn</td>
<td>Mean</td>
<td>19.07</td>
<td>26.59</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>3.43</td>
<td>6.56</td>
<td>21.18</td>
</tr>
<tr>
<td></td>
<td>Both combined</td>
<td>Mean</td>
<td>19.33</td>
<td>26.22</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>3.32</td>
<td>7.34</td>
<td>14.13</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>19.07</td>
<td>26.70</td>
<td>32.24</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.79</td>
<td>7.98</td>
<td>9.07</td>
</tr>
</tbody>
</table>

Results indicated that artificially restricted participants were always faster in the unrestricted condition compared to other conditions. This result would be expected as this was the easiest and most familiar condition.

For most permutations of the test, the artificially restricted participants took longer on average in the device conditions than in the restricted condition. However, these differences were not always significant. The gooseneck mirror was significantly slower than the restricted condition at both right turns and the difference between the junction camera and the restricted condition approached significance at both right turns. There were no significant differences between the restricted and device conditions for left turns.

There were no within condition significant differences between the artificially restricted and the validation participant group. This suggests that the two groups were broadly comparable in terms of time taken to make the turn and that the artificial restriction was a valid approximation of people with restricted movement for this measure.
Figure 56 Mean time taken to make a right turn at the acute angle junction

The pattern of results within the validation participant group was consistent with that of the artificially restricted with only a few slight differences. For example, the junction camera was found to be significantly slower than the without devices condition at the 90° angle junction left turn. For one of the permutations (acute angle junction right turn) the junction camera was found to be significantly slower than the gooseneck mirror.

9.4.2.3 Ease of checking ratings

For all permutations of the test artificially restricted participants had the same patterns of ratings. The unrestricted condition was always rated significantly more highly than all other conditions. The restricted condition was always rated lower (less easy) than both the junction camera and gooseneck mirror conditions. Participants found the junction camera easier to use for checking the junction was clear than the gooseneck mirrors and this difference was significant for all cases except for the right turn at the acute angle junction.
Validation participants gave significantly higher ratings for ease of checking in the restricted/without devices condition than artificially restricted participants. For most permutations the validation participants did not find the observation aids conditions to be significantly easier or more difficult than the without device condition. At the acute angle junction left turn the junction camera was rated significantly higher than the without devices condition by validation participants. Validation participants were consistent with the artificially restricted participants in that they seemed to have a preference for the junction camera over the gooseneck mirror and this difference was significant in some cases.

9.4.2.4 Confidence ratings

The artificial restriction imposed on the main participant group significantly decreased confidence compared to the unrestricted condition. Both the junction camera and gooseneck mirror produced an increased rating of confidence compared to the restricted/without devices condition. However, the ratings in the device condition were still significantly lower than those in the unrestricted condition. For all permutations the difference between the junction camera and gooseneck mirror was significant or near significant. The junction camera was favoured.

Validation participants were significantly more confident than the artificially restricted participants in the restricted/without devices condition. There were no significant differences between the without devices and the junction camera conditions with the exception of the acute angle junction left turn where the junction camera significantly improved confidence compared to having no aids. The gooseneck mirrors tended to significantly decrease confidence compared to the without devices condition and were rated as significantly worse than the junction camera for most permutations of the test.
9.4.2.5  Quality of view

Within the artificially restricted group, the pattern of ratings for quality of view was very similar to that of confidence. The junction camera was generally rated as an improvement in comparison to the restricted/without devices condition and was favoured over the gooseneck mirrors. The gooseneck mirrors produced a small but significant improvement in quality of view at the acute angle junction but not that the 90° angle junction.

Validation participants rated the quality of view highly in the without devices condition. Within this group, the gooseneck mirrors were rated significantly lower than the without devices condition and the junction camera for most permutations of the test.

9.4.2.6  Subjective comments on the junction usability task

In the unrestricted condition, it was commonly reported by the participants that it was possible for them to move to enable them to see round the bend to the left at the 90° angle junction and that, although there was a bend to the right the view was clear. The acute angle junction was not seen to be problematic either.

In the restricted condition, for both junctions and both directions, it was reported that it was very difficult to see far enough. Some thought it was too dangerous to pull out of the junction and three of the ten participants would not pull out at the 90° angle junction in either direction and two would not pull out of the acute angle to the left. It was common for participants to express their desire to perform similar compensatory behaviours as highlighted in the user survey, such as creeping forwards, avoiding turning right, waiting longer until there is more certainty, positioning the vehicle differently, and asking a passenger for advice. This adds validity to the trials.

Junction camera

The junction camera was generally thought to give a better additional and un-obscured view than in the restricted condition and was considered a useful aid. There were some trust issues raised with concerns over judging distance, speed and size of objects correctly, but for most this seemed to reduce with practice.

The buttons also seemed to create a problem, with confusion over which view was displayed (sometimes not consciously), turning off the display accidentally, and difficulty turning it off again once the manoeuvre was completed. One participant actually forgot to look left when turning right, which could be due to the demand placed on their attentional capacity. Another participant thought that it would be preferable to be able to see both views at the same time as it was not possible to switch between them quick enough, but another two already thought the screen was too small. Some participants also expressed that the angle and positioning of the camera was not ideal, more so at the 90° angle junction than at the acute angle junction. Other problems identified by participants more rarely were due to glare from the sun, rain spots on the lens, reflection on the image, and a change in light leading to a need to alter the contrast of the image.

It was seen in the validation phase that in the condition without devices, similar compensatory actions were taken as highlighted in the user survey. The usability issues raised by the participants in the main phase were echoed by those in the validation phase. However, three of the four participants in the validation phase actually used the junction camera differently by using the camera display to show them one view (usually the right view for the 90° angle junction) and looking the other way. Additional issues raised included one participant using hand controls having to let go of the steering wheel to use the buttons in order to change the view provided, and another reporting that mirrors would also have to be used in conjunction with the junction camera system.
Gooseneck mirror

Although it was recurrently reported by those in the main phase that they felt the mirrors could possibly be beneficial by providing an extra view (but not as good as unrestricted), all but one of the four disabled participants felt there was no potential in them, one of them expressing very strongly that “if reliant on these in real life, it would be suicide”. One participant in the main phase would not pull out of either junction to the right.

The main usability problem experienced by participants (both the main and validation phases) was the A pillar and other internal features of the car being displayed in the gooseneck mirror causing obscuration as well as distraction. A second problem was that the mirrors were actually in the direct line of vision. The same comments were made about the mirrors irrespective of the junction or whether turning left or right out of the junction, with all participants feeling uncomfortable with the perceived distortion of size/distance of the image displayed. Many participants found the mirrors difficult to adjust and to get the correct position, and they actually fell off for a couple of participants. Other problems identified more rarely included glare from the sun, reflections, uncertainly about whether to wear driving glasses to look at the image, and incompatibility of the gooseneck mirrors with the sun visor.

9.4.2.7 Summary of junction usability results

- Artificially restricted participants were significantly faster in the unrestricted condition compared to all other conditions for most permutations of the test.
- The observation devices did not offer benefit in terms of making the process of checking a junction faster in the circumstances of this trial. In fact, the gooseneck mirror and junction camera tended to require more time to check the junction was clear than the without devices condition. This was especially evident at right turns. This is presumably due to the need to switch between views. The device conditions were unfamiliar to the participant and this may account for the result.
- Artificially restricted participants found the junction camera and gooseneck mirror to be beneficial in terms of ease of detection, confidence and quality of view despite the additional time required to make the checks.
- Both groups of participants displayed a preference for the junction camera over the gooseneck mirror. This preference was more strongly observed within the validation participants.
- Validation participants rated ease of checking, confidence and quality of view significantly higher in the restricted/without devices condition than the artificially restricted participants. The without devices benchmark for comparison was therefore higher and there was less potential for improvement by the observation aids.
- Within the validation group, ratings for the junction camera were not significantly different from the without devices condition for most measures and permutations. The left turn at the acute angle junction was an exception where the junction camera was found to make checking easier and to improve participants’ confidence. This turn was most difficult of the four as the position of the vehicle results in the further distance to turn to see traffic from the right.
- Within the validation group, the gooseneck mirror was rated significantly lower than the without devices condition for measures of confidence and quality of view.
- Participant comments and observations of usability problems were consistent with the findings from the participant ratings and the issues predicted during the heuristic evaluation.
9.4.3 Reverse parking

9.4.3.1 Conditions and measures

Six conditions were examined during the reverse parking task:

1. Unrestricted (Unr) With no restriction and no observation aids (artificially restricted participant group only)
2. Restricted/Without Device (R/WOD) Artificially restricted participants wore the neck brace and validation participants drove as they normally would. No observation aids were used.
3. Reversing camera (RC) Restricted (artificially or genuinely) but aided by the Reversing Camera
4. Visual Sensor (VS) Restricted (artificially or genuinely) but aided by the Visual Sensor
5. Audible Sensor (AS) Restricted (artificially or genuinely) but aided by the Audible Sensor
6. Panoramic mirror (PM) Restricted (artificially or genuinely) but aided by the panoramic mirror

The reverse park task collected eight difference measures:

1. Time- the time taken to complete the reverse parking task
2. Critical Exceedances- the number of critical exceedances (e.g. crossing the line or touching a cone) made during the task
3. Quality- a subjective quality-rating of the reverse parks made by the 10 independent raters on a 10-point scale in response to the question: “How well or badly do you think that the car is parked in the space?”
4. Ease of Reversing- a subjective rating of the how easy the participant felt it was to reverse into the space on a 10-point scale in response to the question: “How easy or difficult was it to reverse into the space?”
5. Confidence- a subjective rating of the how confident the participant felt by the on a 10-point scale in response to the question: “How confident or unconfident did you feel reversing into the space?”
6. Helpfulness of aid- a subjective rating of the how helpful the participant felt that the devices were on a 10-point scale in response to the question: “How helpful or unhelpful was this reversing aid?”
7. Ease of use of aid- a subjective rating of the how easy the participant felt that the devices were to use on a 10-point scale in response to the question: “How easy or difficult was the reversing aid to use?”
8. Reliance on aid- a subjective rating of the how much the participants relied on the reversing aids on a 10-point scale in response to the question: “How easy or difficult was the reversing aid to use?”

Full analysis of each measure for each permutation of the reverse parking test is reported in Appendix I. The key findings of the analysis are described in the following sections.

9.4.3.2 Time

Figure 58 shows the mean time taken for both artificially restricted and validation participants. For the artificially restricted group, it took less time to complete the task in the unrestricted condition than in any other condition. The comparison between the restricted and unrestricted conditions for time taken to complete the reversing task approached significance; it took longer to complete the task in the restricted condition than in the unrestricted condition.
When comparing all device conditions (separately) to the restricted condition, it took significantly longer to complete the reverse parking task in the visual and audible sensor conditions than in the restricted condition. These results show that none of the devices significantly improve performance in terms of the time taken to complete the task.

When the device conditions were compared (separately) with the unrestricted condition, it took significantly longer to complete the reverse parking task in the visual sensor, audible sensor and panoramic mirror conditions than it did in the unrestricted condition. None of the devices compensated to the level of the unrestricted driver for this measure.

When comparing all of the devices with each other, there was only one pair where a significant difference was observed; it took significantly longer to complete the reverse parking task in the Visual sensor condition than it did in the Panoramic mirror condition.

In the validation group, it took significantly longer in the visual sensor and panoramic mirror conditions than it did in the without device condition.

The task took longest to complete in audible sensor condition for the artificially restricted participants and in the reversing camera condition for the validation participants. The validation participants’ times in the without devices condition tended to be faster than the artificially restricted participants’ times in the restricted condition. However, these differences were not significant, indicating that the two groups were broadly comparable in terms of the time taken to complete the reverse park task. It also suggests that the restricted condition was a valid approximation of people with restricted movement for this measure.

The pattern of results differed between the two groups. For the artificially restricted group, when comparing all of the devices with each other, it took significantly longer to complete the reverse parking task in the visual sensor condition than it did in the panoramic mirror condition. In the validation group, when the devices were compared with each other, there were no significantly different pairs.
Figure 58 Mean time taken to complete the reverse park, artificially restricted and validation participants

9.4.3.3 Critical Exceedances

For both the artificially restricted participants and the validation participants, there were no significantly different pairs in terms of the numbers of critical exceedances made in any of the comparisons. Participants did not make significantly more critical exceedances in the restricted condition nor did they make significantly fewer critical exceedances in the device conditions; this suggests that the presence of the devices did not have any affect on whether the participant made any critical exceedances.

9.4.3.4 Quality of Reversing

For both participant groups, there were no significantly different pairs in terms of the quality of parking ratings that were given in any of the comparisons. This shows that the quality of parking was neither improved nor reduced by use of observation devices.

9.4.3.5 Ease of Reversing

Figure 59 shows the ease of reversing ratings for both artificially restricted and validation participants. For the artificially restricted participants, it was significantly easier to reverse into the space in the unrestricted condition than it was in the restricted condition. Participants gave significantly lower subjective ratings for ease of reversing in the devices conditions than in the restricted condition; no devices were found to make the task significantly easier.
When comparing each of the device conditions with the unrestricted condition, it was considered significantly easier to complete the reverse parking task in the unrestricted condition compared with all device conditions. None of the devices tested could compensate to the level of an unrestricted driver for this measure.

The results show that for the validation participants, the reverse parking task was rated as being significantly easier in the without device condition than in the panoramic mirror condition. This suggests that the panoramic mirror maybe not be a useful device for this particular task.

When comparing device conditions with other device conditions in the artificially restricted group, there was a difference which approached significance in the perceived ease of reverse parking for one pair of devices; it was easier to complete the task in the audible sensor condition than it was in the visual sensor condition.

When the devices were compared with one another for how easy the validation participants found completing the reversing task, it was found that the reversing camera condition made the task significantly easier than the audible sensor and the panoramic mirror conditions for the validation participants.

![Box plot showing ease of reversing rating](image)

**Figure 59 Ease of reversing rating, artificially restricted and validation participants**

9.4.3.6 Confidence

Figure 60 shows the confidence ratings for both groups of participants. Artificially restricted participants rated themselves as feeling significantly more confident in the unrestricted condition than in the restricted condition (and indeed, any other condition). When all device conditions were compared with the restricted condition for confidence ratings, there were no
significantly different pairs; no devices were found to significantly improve artificially restricted drivers’ confidence in this task.

When the device conditions were compared with other device conditions, it was significantly easier to complete the task in the reversing camera condition than it was in the visual sensor condition. However, the reversing camera did not compensate to the level of the unrestricted driver.

In the validation participant group, participants appeared to feel most confident using the reversing camera, and least confident using the panoramic mirror. When the devices were compared (separately) to the without device condition, none of the devices were found to significantly improve the participants’ confidence ratings. When the devices were compared with each other in terms of confidence ratings provided by the validation participants, there were four different pairs which approached significance:

- Reversing camera vs. audible sensor
- Reversing camera vs. panoramic mirror
- Visual sensor vs. panoramic mirror
- Audible sensor vs. panoramic mirror

![Confidence ratings, artificially restricted and validation participants.](image)

### 9.4.3.7 Helpfulness

The helpfulness ratings of the devices (for both the artificially restricted and the validation participants) can be seen in Figure 61. For the artificially restricted participant group, the audible sensor was considered to be the most helpful device (mean=6.8); the panoramic mirror was considered to be the least helpful device (mean=1.8). When comparing the devices
with each other for helpfulness, the artificially restricted participants rated the panoramic
mirror as being significantly less helpful than any other device for this task.

For the validation participants, the reversing camera was considered to be the most helpful
device (mean=8.75), as with the artificially restricted group, the panoramic mirror was rated
as being the least helpful device (mean=2.0). When the device conditions were separately
compared with each other for the perceived helpfulness, there were three significant pairs; the
reversing camera condition was rated as being significantly more helpful than the visual
sensor and panoramic mirror conditions, the audible sensor was rated as being significantly
more helpful than the panoramic mirror.

Figure 61 Helpfulness of device rating, artificially restricted and validation participants

9.4.3.8 Ease of use of device

Both groups of participants’ ratings of ease of use of the devices are shown in Figure 62. For
the artificially restricted participants, when the device conditions were compared with each
other, the visual and audible sensors were rated as being significantly more easy to use for the
reversing task than the panoramic mirror was.

For the validation participants, the difference between the audible sensor and the panoramic
mirror conditions approached significance (the audible sensor was rated as being more helpful
than the panoramic mirror). When the device conditions were separately compared with each
other for the perceived helpfulness, there were three significant pairs; the reversing camera
condition was rated as being significantly more helpful than the visual sensor and panoramic
mirror conditions, and the audible sensor was rated as being significantly more helpful than
the panoramic mirror. Across both groups, there were no other significantly different pairs.
The ratings of reliance on the reversing aids for both groups of participants can be seen in Figure 63. For the artificially restricted participants, the audible sensor was the device which was most relied upon (mean=8.0); the panoramic mirror was the device rated as being relied on the least (mean=2.0).

When comparing the devices with each other for reliance, the panoramic mirror was rated as being significantly less relied on than any other device for this task.

For the validation participants, the reversing camera was the device which was most relied upon (mean=8.75); the panoramic mirror was the device rated as being relied on the least (mean=2.75). When the devices were compared with each other for reliance, the validation participants rated themselves as relying significantly more on the audible sensor than on the panoramic mirror.
Validation Participants n=4
Artificially Restricted n=10

Participant Group

Reliance Rating

Condition
- Reversing Camera
- Visual Sensor
- Audible Sensor
- Panoramic Mirror

Figure 63 Mean rating of reliance on device, artificially restricted and validation participants

9.4.3.10 Subjective comments on the reverse parking task

Unrestricted, no problems were reported with carrying out this task, although one participant was observed carrying out the manoeuvre by leaning out of the car with the door open. When restricted, generally the mirrors were relied upon, although a couple expressed that it was “guesswork” and that they were unable to see the cones.

Reversing camera

Although all four of the participants in the validation phase found the reversing camera beneficial and most of those in the main phase found it useful particularly in a straight line, some problems were identified. The main problem related to judgements about distance and location of objects, but this was thought to be minimised with practice. Some also reported that they were unable to see the cones, that the view provided by the camera was too high too narrow to show them, and two participants did not appear to use the reversing camera but still used the mirrors.

Audible reversing sensors

Although participants generally thought the audible reversing sensors prevented them from knocking into something and allows good use of the space, the main problem was that they were not informed about the location of the object about which the sensors were warning them, particularly to the sides of the car. It was identified that this feedback system enabled them to use the mirror to identify the objects and that in combination, this device was useful. It was identified by some participants that interpretation of the beeps would take some time. All four of those in the validation phase found the audible reversing sensors highly beneficial,
although (as in the main phase) one thought that identification of the location of the object was not immediately obvious using this device.

**Visual display for reversing sensors**

Comments from participants about the visual display for reversing sensors was mixed. Some felt that it was unreliable as it was inconsistent in terms of when it would warn about objects and others found it difficult to trust the information, although these issues could both be related to becoming used to the device through practice. Some reported that it allowed good correctional behaviour in terms of direction and full use of the space in terms of distance. However, it was also not uncommon for participants to find it distracting and confusing when trying to use the door mirrors as well. Several had to adjust the angle of the rear view mirror to enable them to see the visual display and some found that the lights were not sufficiently visible to them. These issues were reflected by those in the validation phase. Three of the four validation participants thought this device would be useful in combination with other devices, such as the audible sensors. The fourth did not like this system and reported that they used their own judgement because the lights did not come on.

**Panoramic mirror**

The panoramic mirror was found by all participants, including those in the validation phase, not to be beneficial for this task as the cones/lines could not be seen in the mirror. Distortion of the image was also seen as a potential problem. One participant also highlighted that it blocked the forward view and another found that it was incompatible with the sun visor.

9.4.3.11 **Reverse parking summary of results**

- The unrestricted condition (artificially restricted participants only) was significantly better than all other conditions at all permutations and for all measures.
- It took longer in all device conditions than in the restricted/without device conditions for both the artificially restricted and the validation participants.
- For artificially restricted participants, the reversing camera system increased ratings of confidence, ease of use and quality of parking and reduced the number of critical exceedances made.
- Ratings of confidence and ease of use were increased and the number of critical exceedances made was reduced when the validation participants used the reversing camera system.
- The panoramic mirror was rated as being the least helpful, least easy to use and least relied upon of the four devices by both groups of participants.
- Artificially restricted participants rated the audible sensor as being the device which was most helpful, easy to use and most relied upon, while validation participants rated the reversing camera as the most helpful, easy to use and most relied upon reversing device.
9.4.4 Turn in the road

9.4.4.1 Conditions and measures

Six conditions were examined during the turn in the road task:

1. Unrestricted (Unr)- With no restriction and no observation aids (artificially restricted participant group only)

2. Restricted/Without Device (R/WOD) - Artificially restricted participants wore the neck brace and validation participants drove as they normally would. No observation aids were used.

3. Reversing Camera (RC) - Restricted (artificially or genuinely) but aided by the Reversing Camera

4. Visual Sensor (VS) - Restricted (artificially or genuinely) but aided by the Visual Sensor

5. Audible Sensor (AS) - Restricted (artificially or genuinely) but aided by the Audible Sensor

6. Panoramic Mirror (PM) - Restricted (artificially or genuinely) but aided by the Panoramic Mirror

The turn in the road task collected five difference measures:

1. Time - the time taken to complete the reverse parking task

2. Percentage of Flashes seen- the percentage of flashes from the second vehicle/bike seen by the participant while completing the task

3. Ease of turn - a subjective rating of the how easy the participant felt it was to reverse into the space on a 10-point scale in response to the question: “How easy or difficult was it to complete the turn in the road?”

4. Confidence - a subjective rating of the how confident the participant felt by the on a 10-point scale in response to the question: “How confident or unconfident did you feel completing the turn in the road?”

5. Helpfulness of aid - a subjective rating of the how helpful the participant felt that the devices were on a 10-point scale in response to the question: “How helpful or unhelpful was this reversing aid?”

Full analysis of each measure for each permutation of the blind spot scenario test is reported in Appendix I. The key findings of the analysis are described in the following sections.

9.4.4.2 Time

The artificially restricted participants completed the turn in the road fastest in the unrestricted condition and most slowly in the panoramic mirror condition. There was no significant difference between the time taken to complete the turn in the road in the restricted condition compared with the unrestricted condition.

Comparing the devices to the unrestricted condition, it was found that the mean time taken to complete the turn in the unrestricted condition was significantly lower than in the audible sensor condition. The comparison between the unrestricted condition and the reversing camera and panoramic mirror conditions approached significance. This shows that no device adequately compensated to the level of an unrestricted driver for this measure.

For the artificially restricted participants, when all device conditions were compared separately with the restricted condition, it took significantly longer for the artificially restricted participants to complete the task in the reversing camera and visual sensor
conditions than it did in the restricted condition. The comparison between the unrestricted condition and the reversing camera and panoramic mirror conditions approached significance.

For the validation participants, it took significantly less time for them to complete the turn in the road in the reversing camera and audible sensor conditions than in the without device conditions. It took longer to complete the task in the panoramic mirror and visual sensor conditions than it did in the without device conditions. When the devices were compared with each other, it was found that the task took significantly longer in the panoramic mirror condition than it did in the reversing camera condition. This suggests that for the validation participants, reversing devices such as reversing camera systems may help to compensate for restricted neck and trunk movement for this measure.

9.4.4.3 Percentage of flashes

Figure 64 shows the mean percentage of flashes seen for both groups of participants. For the artificially restricted participants, when the restricted and unrestricted conditions were compared, more flashes were seen in the unrestricted condition; this difference approached significance.

When each device was compared with the restricted condition, there were no significantly different pairs, suggesting that no device could compensate for impaired function for this measure.

When all device conditions were compared with the unrestricted condition, a significantly higher percentage of flashes were seen in the unrestricted condition than in the visual and audible conditions and the panoramic mirror condition.

The validation participants actually saw a significantly higher percentage of flashes in the reversing camera condition than they did in the without device condition, however, in all other device conditions, they saw fewer flashes in the device conditions than in the without device condition. This is consistent with the artificially restricted participants’ results and suggests that the participants were focussing more attention than they should have looking at the devices rather than looking out of the windows. Training may be required to reduce distraction effects caused by devices.
Figure 64 Mean percentage of flashes seen, artificially restricted and validation participants

9.4.4.4 Ease of turn

Figure 65 shows the ease of turn ratings for both groups of participants. Both groups found completing the turn in the road easiest in the reversing camera condition and most difficult in the panoramic mirror condition.

The artificially restricted participants found it significantly easier to perform the turn in the road in the unrestricted condition than in the restricted condition. In fact, the artificially restricted participants found it significantly easier to perform the turn in the road in the unrestricted condition than in any other condition.

The artificially restricted participants rated completing the task as being significantly easier in the reversing camera and audible sensor conditions than in the restricted condition. The results suggest that for this measure, these two devices do compensate for the restricted movement to some degree. It was not the case that all devices were more helpful than the restricted condition; the artificially restricted participants rated the task as being significantly easier to complete in the restricted condition than in the panoramic mirror condition.

When device conditions were compared with the unrestricted condition, artificially restricted participants found it significantly easier to complete the turn in the unrestricted condition than in the reversing camera, audible sensor and panoramic mirror conditions. This finding shows that while the reversing camera and audible sensors did compensate for the restricted movement, the compensation was not to the level of an unrestricted driver.
For the validation participants, no significant differences were found when the device conditions were compared with the without device condition, however, the validation participants rated it as being easier to complete the task in the without device conditions than in the visual sensor and panoramic mirror conditions. When the devices were compared with each other in the validation phase, participants rated completion of the task as being significantly easier in the reversing camera condition than in either the visual sensor or the panoramic mirror conditions.

When device conditions were compared with other device conditions, artificially restricted participants rated the turn as being significantly easier in the visual and audible sensor conditions than in the panoramic mirror condition.

Figure 65 Ease of turn ratings for artificially restricted and validation participants

9.4.4.5 Confidence

Figure 66 shows the confidence ratings for both groups of participants. Patterns of confidence ratings were consistent with the ease of turn results.

Unsurprisingly, the artificially restricted participants rated themselves as feeling significantly more confident in the unrestricted condition than in the restricted condition (and indeed, any other condition).

A surprising finding was that both of the participant groups felt more confident completing the task in a restricted state with no assistance than they did in certain device conditions. The artificially restricted participants rated themselves as feeling significantly more confident in the restricted condition than in the panoramic mirror condition. While the validation participants rated themselves as feeling significantly more confident without the assistance of any devices than they did when they used the visual sensor. This suggests that certain observation devices may even worsen the effect of the drivers’ restrictions.
When all of the device conditions were compared with each other, the artificially restricted participants rated themselves as feeling significantly more confident in the reversing camera condition than in the panoramic mirror condition.

The validation participants rated themselves as feeling most confident in the reversing camera condition and least confident in the panoramic mirror conditions. They also felt significantly more confident in the audible sensor condition than they did in the visual sensor condition.

![Confidence rating for artificially restricted and validation participants](image)

**Figure 66 Confidence rating for artificially restricted and validation participants**

### 9.4.4.6 Helpfulness of aid

Figure 67 shows the helpfulness ratings for both groups of participants. Both participant groups rated the reversing camera as the most helpful aid, and the panoramic mirror as the least helpful aid. For the artificially restricted participants, when device conditions were compared with each other for perceived helpfulness, no device was significantly more helpful than any other, however, the comparison between the reversing camera and visual sensor approached significance.

For the validation participants, the audible sensor was considered to be significantly more helpful in this task than the visual sensor was. The audible sensor was also rated as being significantly more helpful than the panoramic mirror.
Figure 67 Helpfulness rating for artificially restricted and validation participants

9.4.4.7 Subjective comments on the turn in the road task

Reversing camera
Most of the participants in the main trials felt that the reversing camera offered marginal benefits for this task. Issues relating to trust, interpretation of the image shown, size of the screen and image, and clarity of the image were all raised by participants as in the reverse parking task. All four of the participants in the validation phase also found the reversing camera useful in this task, reporting that it was very clear, would be ideal in combination with the audible reversing sensors, but that it may take some time to become used to it, particularly in high-demand situations, and in terms of judging distances.

Audible reversing sensors
Participants in both the main and validation phase generally found the audible reversing sensors beneficial for this task. It was reported to be useful for getting close to the kerb, manoeuvring the car backwards, easy to use whilst doing other tasks and compatible to use in combination with other devices, particularly the reversing camera. A couple of participants in the main phase found it inconsistent and insufficiently responsive.

Visual display for reversing sensors
A few participants found this beneficial to inform them of the location of the kerb whilst a couple did not even attempt to use the information from the display. Issues which were raised included that it did not assist with checking other traffic, was difficult to see in bright sun, provided inconsistent information or the lights did not come on, and gave the participant too much visual information to deal with. Those in the validation phase also felt that the
information from the display did not offer an additional benefit and issues reflected those found in the main phase.

**Panoramic mirror**

Seven of the ten participants in the main phase and three of the four in the validation phase did not find the view provided by the panoramic mirror offered an additional beneficial view for this task. Other issues highlighted were similar to those raised before, particularly in terms of distraction caused by the information in the mirror which was irrelevant to the driving task.

9.4.4.8 **Turn in the road summary of results**

- The unrestricted condition (artificially restricted participants only) was significantly better than all other conditions at all permutations and for all measures.
- For both groups of participants, it took longer to complete the turn in the road in all of the device conditions than it did in the restricted condition. For the validation participants, the reversing camera and audible sensor allowed the participants to complete the task more quickly than in their usual without device driving condition.
- Both groups of participants appeared to focus more attention on the devices than on attending to the number of flashes seen outside the vehicle; this suggests that certain devices are somewhat distracting to novice users.
- Of all device conditions, both groups of participants rated the task as being easiest in the reversing camera condition and most difficult in the panoramic mirror condition.
- Artificially restricted participants rated themselves as feeling most confident in the audible sensor condition of all device conditions, while validation participants felt most confident in the reversing camera condition; both participant groups felt least confident in the panoramic mirror condition.
- Devices were not always rated as instilling more confidence than the restricted or without device conditions. Validation participants rated themselves as feeling significantly more confident without the assistance of any devices than they did when they used the visual sensor and the artificially restricted participants rated themselves as feeling significantly more confident in the restricted condition than in the panoramic mirror condition.
- For the validation participants, performance for all measures was better using the reversing camera system than their normal without device condition.
- Both participant groups found the reversing camera to be most helpful and the panoramic mirror as being the least helpful device.

9.4.5 **Blind spot scenario**

9.4.5.1 **Conditions and measures**

Four conditions were examined during the turn in the road task:

1. Unrestricted (Unr) With no restriction and no observation aids (artificially restricted participant group only)
2. Restricted/Without Device (R/WOD) Artificially restricted participants wore the neck brace and validation participants drove as they normally would. No observation aids were used.
3. Blind Spot Mirror (BSM) Restricted (artificially or genuinely) but aided by the Blind Spot Mirror
4. Panoramic Mirror (PM) Restricted (artificially or genuinely) but aided by the Panoramic Mirror

The blind spot scenario task collected five difference measures:

1. **Quality** - a subjective rating of the quality of the participants’ view of vehicle approaching from behind on a 10-point scale in response to the question: “How good or poor was your view of the vehicle approaching from behind?”

2. **Clarity** - a subjective rating of the clarity of the participants’ view of vehicle approaching from behind on a 10-point scale in response to the question: “How clearly or ambiguously could you see the vehicle approaching from behind?”

3. **Judgement of speed** - a subjective rating of the how easy or difficult the participants’ found it to judge the speed of a vehicle approaching from behind on a 10-point scale in response to the question: “Easy or difficult was it to judge the speed of the vehicle approaching from behind?”

4. **Judgement of position** - a subjective rating of the how easy or difficult the participants’ found it to judge the position of a vehicle approaching from behind on a 10-point scale in response to the question: “Easy or difficult was it to judge the position of the vehicle approaching from behind?”

5. **Confidence** - a subjective rating of the how confident the participant felt by the on a 10-point scale in response to the question: “How confident or unconfident would you feel making a lane change using this observation method?”

6. **Helpfulness of aid** - a subjective rating of the how helpful the participant felt that the devices were on a 10-point scale in response to the question: “How helpful or unhelpful was this reversing aid?”

The blind spot scenario was repeated at two different speeds, full analysis of each measure for each permutation of the blind spot scenario test is reported in Appendix I. The key findings (having calculated an average across both speeds) of the analysis are described in the following sections.

9.4.5.2 **Quality of view**

In the artificially restricted group of participants, overall, quality of view ratings were highest in the unrestricted condition and lowest in the blind spot mirror condition. The quality rating was significantly higher in the unrestricted condition compared with the unrestricted condition (and all other conditions).

There were no other significantly different pairs in this comparison.

Overall, the validation participants’ quality of view ratings were highest in the without device condition and lowest in the blind spot mirror condition. As with the artificially restricted participants, the quality of view was rated as being higher in the without device condition (mean = 8.0) than in the blind spot mirror condition (mean = 3.4), this difference approached significance. The panoramic mirror was rated as giving a better quality of view than that recorded in the without device condition, and so to a degree, compensated for the validation participants’ restricted movement, but this difference was not statistically significant.
9.4.5.3 Clarity of view

Figure 69 shows the clarity of view ratings for both groups of participants. Overall, the artificially restricted participants’ clarity of view ratings were highest in the unrestricted condition (mean =9.55), and lowest in the blind spot mirror condition (mean =8.1). The mean clarity of view ratings were significantly higher in the unrestricted condition than in the restricted condition.

When the device conditions were separately compared with the restricted condition, there were no significantly different pairs. The mean clarity of view ratings in the unrestricted condition were significantly higher than in the blind spot mirror condition. When the blind spot mirror and the panoramic mirror were compared with each other, the result approached significance. The panoramic mirror (mean=9.0) was rated as providing a better clarity of view that the blind spot mirror was (mean=8.1). These findings suggest that the panoramic mirror might be better at providing a clear view of the blind spot for restricted drivers, but that neither of the devices compensate to the level of an unrestricted driver.

Overall, validation participants’ clarity of view ratings were highest in the without device condition (mean =8.0), and lowest in the blind spot mirror condition (mean =3.6). When the device conditions were separately compared with the without device condition, there were no significantly different pairs.

When the blind spot mirror and the panoramic mirror were compared with each other using the validation participants’ data, the result approached significance; the panoramic mirror (mean=9.25) was rated as providing a better clarity of view than the blind spot mirror.

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Figure 68 Quality rating for artificially restricted and validation participants
(mean=3.6). These findings suggest that the panoramic mirror might be better at providing a clear view of the blind spot for restricted drivers.

![Clarity of view rating for artificially restricted and validation participants](image)

**Figure 69 Clarity of view rating for artificially restricted and validation participants**

### 9.4.5.4 Judgement of speed

Figure 70 shows both groups of participants’ ratings of how easy or difficult they found it to judge the speed of a vehicle approaching them from behind. The artificially restricted participants rated the ability to judge the speed of an approaching vehicle most highly in the unrestricted condition and lowest in the blind spot mirror condition. The artificially restricted participants rated it as being significantly easier to judge the speed of the approaching vehicle in the unrestricted condition than in the restricted condition (and indeed any other condition).

When the device conditions were compared to the restricted condition, there were no significant pairs. Similarly, when devices were compared with each other, neither device was rated as bettering artificially restricted participants’ judgement of speed.

The ability of the validation participants to judge the speed of an approaching vehicle was rated highest in the panoramic mirror condition and lowest in the blind spot mirror condition for the validation participants. When the device conditions were compared with each other, the ability to judge the speed of the approaching vehicle was easier in the panoramic mirror condition than it was in the blind spot mirror condition. As the rating for ease of speed judgement was highest in the panoramic mirror condition, this suggests that the panoramic mirror compensates for restricted neck and trunk movement in the judgement of speed.
9.4.5.5 **Judgement of position**

Figure 71 shows both groups of participants’ ratings of how easy or difficult they found it to judge the position of a vehicle approaching them from behind. The artificially restricted participants’ ability to judge the position of an approaching vehicle was rated as being most difficult in the blind spot mirror condition, and easiest in the unrestricted condition. The position of the approaching vehicle was rated as being significantly easier to judge in the unrestricted condition than in the restricted condition. It was also found to be easier to judge the position of the approaching vehicle in the restricted condition than any of the device conditions. There were no other significant pairs in the comparison.

The validation participants’ ability to judge the position of an approaching vehicle was rated as being most difficult in the blind spot mirror condition, and easiest in the panoramic mirror condition. When the device conditions were compared with each other, the ability to judge the position of the approaching vehicle was rated as being significantly easier in the panoramic mirror condition than it was in the blind spot mirror condition.
9.4.5.6 Confidence

Confidence ratings for both groups of participants can be seen in Figure 72. The artificially restricted participants’ confidence rating was significantly higher in the unrestricted condition compared with the restricted condition. When the unrestricted condition was compared with the device conditions, artificially restricted participants’ confidence ratings were significantly higher in the unrestricted condition than they were in the device conditions. There were no other significant differences, although the device comparison between the blind spot mirror and panoramic mirror conditions approached significance. It is thought that neither of the devices adequately compensate to the level of the unrestricted driver.

Validation participants’ confidence ratings were highest in the panoramic mirror condition and were lowest in the blind spot mirror condition. The validation participants rated themselves as feeling more confident in the panoramic mirror condition than they did in their normal without device condition; and, although not significant, this suggests that the panoramic mirror may compensate for their impaired function to a degree.
Helpfulness ratings can be seen in Figure 73. When the two blind spot devices were compared with each other and rated for their helpfulness, both groups of participants rated the panoramic mirror as being significantly more helpful than the blind spot mirror for this task.
9.4.5.8  Subjective comments on the blind spot scenario task

In the unrestricted condition, some participants identified that there was a short time when they could not see the second car. When restricted participants were not able to move their head to try to see the car and one expressed that they were unable to use the door mirror fully. Three of the four participants in the validation phase felt there was a blind spot in the condition without devices.

Blind spot mirror

There was a tendency for the blind spot mirrors not to be liked for this task, for both the main and validation phase participants. However, there was possibly a misunderstanding of the situation in which the blind spot mirrors were designed to assist as they also felt that the mirror would be useful in low speeds or if the car was close. Other participants did report that there was no longer a blind spot and the second car could be seen for longer than without it just in the door mirror. Some did report that another blind spot was created by the blind spot mirror though as it restricted the view from the door mirror. Problems with distortion of the image (speed and distance judgement) seen in the blind spot mirror were experienced by a couple of participants and this was reflected by those in the validation phase.

Panoramic mirror

It was commonly reported by participants in the main and validation phase that the panoramic mirror could be distracting as it showed too much of the inside of the vehicle and its occupants and that there was some distortion of the image (speed and size judgement). However, six of the ten participants in the main phase and three of the four in the validation phase felt that it eliminated the blind spot which was there without it.

9.4.5.9  Blind Spot Scenario summary of results

- The unrestricted condition (artificially restricted participants only) was significantly better than all other conditions at all permutations and for all measures.
- For both groups, the participants’ quality of view appeared to worsen when they used a blind spot mirror compared with them (being restricted) and using no devices.
- The panoramic mirror was rated as providing both participant groups with a better quality of view than the view where participants were restricted/without devices.
- For both groups of participants, clarity of view ratings were higher in the panoramic mirror condition than they were in the blind spot mirror condition, suggesting that installation of a panoramic mirror may provide restricted drivers with a clearer view of their blind spot.
- Judging the speed and position of a vehicle approaching from behind was deemed as being easier in the panoramic mirror condition than it was in the blind spot mirror condition for both groups of participants. For validation participants, it was easier for them to judge the speed and position of an approaching vehicle in the panoramic mirror condition than in their normal without device condition.
- Artificially restricted participants felt slightly more confident in the panoramic mirror condition than they did in the restricted condition. Validation participants rated themselves as feeling more confident in the panoramic mirror condition than they did in their normal without device condition.
- Both participant groups rated the panoramic mirror as being significantly more helpful than the blind spot mirror for this task.
10 Discussion and conclusions

The following sections draw together the results of all of the different evaluation methods to present an overall picture for each device.

10.1 Junction camera

10.1.1 Ability to compensate for impairment

Field of view measurements showed that the junction camera provided a good view (i.e. down to 15cm from above the ground) of most of the region that was not visible to the severely restricted driver. The camera angle was set appropriately so that, in theory, it would provide a view at a wide range of junctions.

The junction detection user test results were consistent with this and showed that the junction camera could provide benefit in terms of increased detection distance when compared to performance when artificially restricted. This result was clearly evident at the acute angle junction. The junction camera also appeared to produce slight benefit at a 90° angle junction but this was not significant. Detection distance at the 90° angle junction was still reasonably large even when restricted with no aids so there was limited potential for improvement here anyway. The benefit provided did not compensate to the unrestricted detection distance in any permutation of the test.

There is also a question from the user test results over whether the clarity of the screen provided enough detection distance to make the device suitable for use at higher speed junctions. It did not achieve the minimum recommended distance for 30mph at the 90° angle junction or the minimum recommended for 40mph at the acute angle junction.

The validation participants, who had genuine restricted neck and/or trunk movement, could see further at both junctions than the artificially restricted participants could when restricted. The junction camera produced no significant benefit to this group. However, their results were highly variable and it is possible that it would have been of benefit to those with the most severe restriction. Additionally, the junction detection measure does not take into account the cost of achieving a high detection distance in terms of pain or fatigue and the junction camera may have benefits in this respect, if not in terms of increased detection distance.

The junction usability test showed that when using the junction camera it took longer to check the junction was clear than when restricted with no observation aids. This effect was particularly evident for right turns and this may be due to the time needed to switch between views. The additional time required may simply be due to unfamiliarity and use may become quicker with training and/or practice.

10.1.2 Participant opinions

Subjective ratings made by the artificially restricted participant group for ease of detection and confidence were broadly in line with the detection distances achieved (i.e. when detection distance was significantly higher, ratings were significantly higher). Clarity of view was not rated very highly for the junction camera and was on the negative side of the scale on average.
The junction camera was favoured over other devices by participants. This was particularly evident during the usability test where participants were able to use the junction camera dynamically to check junctions were clear before making a turn.

Validation participants did not appear to see a strong benefit of the junction camera in terms of subjective factors such as ease of detection, quality of view and confidence as the ratings they gave in the junction camera condition were not significantly different to those given in the without devices condition for most permutations. However, for one or two permutations of the junction usability test the junction camera was rated as significantly easier than having no aids. The junction camera may therefore have potential to make things easier for those with restricted movement and users may become more positive over time when they have become more accustomed to the technology.

Participant comments on the junction camera were quite positive in general. Some trust and usability issues were identified. These were in line with the issues identified during the expert heuristic evaluation as well as those raised in the consultation phase; these are discussed in more detail in the following section.

10.1.3 Risks in use

There were significant safety and reliability concerns with the particular junction camera studied. The position of the cameras on the lower A-pillars is considered to present a risk of additional or more serious injury if they were contacted in the event of a frontal impact, side impact or rollover. This risk could be mitigated by moving the cameras to a different position, provided that it still provided a useful view and did not conflict with any other vehicle safety features such as curtain airbags.

The interface to control the camera view is directionally incompatible with the views activated (i.e. the left button activated the right camera and vice versa). In addition there is no feedback on the device to tell the driver which view is displayed. The driver is likely to mistake the views and this could easily lead to an accident. The likelihood of confusion is increased as the junction camera would be used in a high workload and time pressured situation. Similarly, accidents that occur in this scenario are likely to be serious. The system design could be improved to correct the flaw in the control interface and to provide easy to read and unambiguous feedback to tell the driver which view they are looking at.

Another potential problem with the junction camera studied was the reversal of the image. This was identified during the heuristic evaluation of the junction camera, which included limited use of the device on public roads. However, this was not commented upon in the user trial phase. This may be because no realistic traffic was included in the junction tasks. The small road system, where the user trials were conducted, is a generic environment without many roadside features and participants may not have perceived the reversal. An on-road pilot of the system is recommended to verify the usability of the system in traffic.

Other problems with the example studied included: the reduction of normal rear view due to the display mechanism used; reduction in quality of view caused by precipitation and bright sunlight and general poor image quality making it hard to see small or low contrast objects. Most of these problems could be designed out, for example, by using a dashboard mounted screen (providing the guidelines in Section 6.4.6 could be followed) and using a better quality camera.
The junction camera studied could be difficult to use when driving using hand controls as it requires buttons to be activated. An alternative design using automatic activation was also examined during the heuristic evaluation. This method was found to have problems. A custom installation for each user would be one way to avoid problems for disabled users. This would also allow the system function to be optimised for the individual, for example, if they required additional view in one particular direction only.

10.1.4 Device conclusions

The junction camera has the potential to increase the view of people with severe restricted neck and/or trunk movement at junctions. Others may still find it a useful aid or back-up to reduce the demand on them when making observations at junctions even if they do not strictly need additional view. The junction camera may be particularly beneficial at difficult junctions such as those with acute angles.

The example evaluated in this study has several quite serious usability issues which give rise to significant safety concerns. As such, we would not recommend that a system with these particular characteristics was used as the sole source of vision at junctions. However, it could have benefit, if the user was to only use the view shown in one direction, i.e. so that they did not have to turn one way. This was indeed how those in the validation phase used the device. The problems with the example system could be addressed through designed out to provide a more reliable and useful system.

The benefit provided by the junction camera in terms of width of field of view and detection distance was approximately equal to that provided by the gooseneck mirrors. In addition, the junction camera did not suffer from the significant blind spot that was evident for the gooseneck mirror. If gooseneck mirrors are considered “acceptable” and are commonly recommended then there is no reason on the basis of this research why the junction cameras should not be equally considered as an acceptable aid to people with restricted movement.

10.2 Gooseneck mirror

The gooseneck mirror was assessed as an aid to seeing left and right at junctions. It has other potential applications which were not assessed, for example, as a reversing aid. Conclusions drawn here therefore apply to use of gooseneck mirrors for use at junctions specifically.

10.2.1 Ability to compensate for impairment

The results of the junction detection task indicated that gooseneck mirrors have the potential to extend the view of a severely restricted person at acute angled junctions. The gooseneck mirror was not significantly better or worse than the junction camera in this respect. The benefit of the gooseneck mirror did not reach the level of the unrestricted condition.

There was no significant benefit at the 90° angle junction, however, participants could see quite far at this junction even when restricted and without devices. There was one permutation of the test at the 90° angle junction where the gooseneck mirror resulted in a slight decrease in detection distance compared to artificial restriction with no observation aids.

The gooseneck mirrors had the advantage over the junction cameras in that they achieved the minimum recommended 40mph detection distance at the acute angle junction whereas the
junction camera did not (Detection distance using the gooseneck mirror was 18.7 metres further on average). However this difference between the two devices was not statistically significant.

Validation participants were able to see further than artificially restricted participants when using no observation aids (i.e. their baseline level of performance was higher than the main participant group). Among the validation participant group the gooseneck mirror significantly reduced detection distance compared to having no devices at the 90° angle junction and provided no significant benefit at the acute angle junction. The gooseneck mirror may therefore actually impair detection at some junctions and any benefits observed may relate to those users with the most severe level of restriction.

The field of view measurements showed that the gooseneck mirror provided a wide view which was even slightly wider than the view provided by the junction camera. The gooseneck mirror therefore has potential to provide significant additional view. However, in the vehicle used for the test, the A pillars created a very large blind spot. The constraints on where the mirrors would adhere to and the length of the gooseneck determined that it was impossible to avoid the A-pillar when trying to adjust the mirrors for the purpose of making observations at junctions. This blind spot appreciably reduces the ability of the gooseneck mirrors to compensate for restricted movement and was remarked upon frequently by participants during the user testing.

This is likely to be a problem in most other vehicles as all will have some kind of A-pillar and limited opportunities to mount the mirrors. Provision of a longer neck may provide a solution to this problem, although this may give rise to different problems, for example, the mirror would then be further from the front of the vehicle and perhaps less likely to provide a view of the junction.

Finally, when using the gooseneck mirror, participants took longer to check that a junction was clear and make a turn compared to using no observation aids. This was under conditions with no traffic and where the gooseneck mirrors were unfamiliar so the time required may not be representative of real world use.

10.2.2 Participant opinions
Artificially restricted participants’ subjective ratings were broadly in line with the detection distances achieved. They found the gooseneck mirror beneficial in terms of ease of checking the junction, confidence and quality of view compared to having no observation aids when restricted.

Clarity of view ratings were still on the negative side of the scale on average even though they were significantly higher than having no aids. This may be due to the distortion of the image caused by the curvature of the mirror and the small size of the mirror.

Validation participants’ ratings were also consistent with the detection distances they achieved. They rated the gooseneck mirror as significantly worse than having no aids for ease of checking, confidence and quality of view. However, their ratings of the without devices condition were quite positive so there was a high benchmark for comparison.
During the static test (junction detection) there were generally very few significant differences in ratings between the junction camera and gooseneck mirror. During the dynamic test, where participants had the opportunity to use the devices to check a junction before making a turn, a clear preference for the junction camera rather than the gooseneck mirror emerged in both participant groups.

The comments given by participants at the end of each test were particularly damning. Validation participants in particular felt that there was no potential in the gooseneck mirrors. Many participants remarked upon problems such as obscuration of normal forward vision, distortion of the image and difficulty of adjustment.

10.2.3 Risks in use

The safety of installation inspection concluded that the gooseneck mirrors would not pose any additional risks in the event of a crash as they are likely to detach from the windscreen and are made of lightweight materials. The occlusion of the normal forward vision is, however, a problem that could increase the risk of an accident occurring.

The blind spot created by the A-pillar has the potential to hide any size of vehicle and would create an increased risk of accident, particularly if the user did not recognise this limitation to their view. The curvature of the mirror causes significant distortion of the image and the wide view results in great detail within a very small display area. This may impair drivers’ ability to make speed and distance judgements. It also gives a confusing and cluttered image from which it is difficult to pick out the relevant information. Potentially, drivers would learn to use the mirrors more effectively with practice and an extensive period of training or familiarisation before use would be recommended.

10.2.4 Device conclusions

The gooseneck mirror(s) can, in theory, provide a wide view which could be a useful aid at junctions to provide additional view to those with severe restriction or to reduce some of the physical workload of this task. This relies on the mirror(s) being placed suitably within the vehicle.

However, constraints on placement within the vehicle and obscuration by interior fittings mean that it is very unlikely to provide an effective aid for this purpose in most vehicles. The example studied in the test vehicle would not be considered to be safe for someone to rely on due to the very large blind spot. In addition, the usability of the image provided is questionable due to the serious distortion of the image.

It would be highly dependent on the particular vehicle and the user’s ability whether the gooseneck mirror could provide any benefit. There are very few modifications that could be made to this device to improve it.

10.3 Reversing aids

All reversing aids (i.e. the reversing camera, visual reversing sensor, audible reversing sensor and panoramic mirror) were assessed during user trials using a reverse park and a turn in the road task. The results showed that the artificial restriction did not result in significantly more critical exceedences or worse quality compared to unrestricted performance during the reverse
park. The artificial impairment did result in significantly less awareness of flashing lights outside the vehicle during the turn in the road task. It was also associated with significantly lower ratings of ease of task and confidence for both the reversing task and the turn in the road task.

According to the study results therefore, restricted movement does not in itself result in an inability to complete reversing tasks, but rather makes them more difficult and perhaps drivers also find it harder to monitor other events in the vicinity. It is also relevant that the results of the junction detection task strongly suggest that the artificial restriction imposed on the user trial participants was more severe than the restriction that is experienced by most people with this disability. This has implications for the evaluation of the devices designed to aid with reversing as it becomes more important that the devices make the task easier rather than increase performance.

There is a possibility that no performance impairment was observed due to the nature of the tasks studied. The method was designed to make the tasks as realistic as possible within the constraints of the closed environment. However, there were elements of the real world that were not incorporated such as the presence of solid obstacles, interactions with other traffic and the possibility of unexpected events or hazards. Participants were unavoidably aware of the safety of the environment and this was likely to affect their behaviour. For example, they may have felt confident to attempt a reversing task when restricted as there were no solid obstacles, or indeed other traffic to consider, but in a real car park they may have made a different decision.

10.4 Reversing camera

10.4.1 Ability to compensate for impairment

The field of view measurements showed that the reversing camera gives an excellent view directly behind the vehicle to the lowest level (i.e. it can show very low objects) and for a good distance behind the vehicle. The only areas not seen are at the rear corners close to the vehicle due to the fact that the single camera is mounted centrally. There would be a risk of striking objects in this area, although no more so using the reversing camera than when using no aids.

The view provided by the reversing camera far exceeded the view of the restricted volunteers who could only see the medium or tallest test objects directly behind the vehicle. The reversing camera was the only device where the view provided actually exceeded the view available to the unrestricted volunteer. However, the benefit of this was not strongly evident in better performance on the reversing tasks.

During the user tests, the reversing camera produced no significant benefits in terms of a reduction in time or critical exceedances or an increase in quality, ease of reversing or confidence during the reverse park task for either the artificially restricted or the validation participants. For the turn in the road task, the reversing camera resulted in a slightly increased time to complete the manoeuvre compared to the restricted without devices condition among the artificially restricted participants. This was the only significant effect. As discussed in section 10.3, there was no observable impairment of task performance in the restricted condition compared to the unrestricted but there were significantly more negative ratings for task difficulty and confidence. The reversing camera did not appear then to compensate for impairment in terms of making reversing easier or increasing confidence.
10.4.2 Participant opinions

Artificially restricted participant ratings of the reversing camera for helpfulness, ease of use and the amount they relied on the device during the task were moderately positive. Validation participants gave even more positive ratings of the reversing camera on these measures. Comments indicated that the reversing camera could offer benefit for reverse parking and turn in the road. It was thought to be particularly beneficial for straight line reversing. Some problems were identified by participants, including the judgement of distances, trust in the system and quality of the image. Participants felt that they would become accustomed to using the system in time.

10.4.3 Risks in use

Overall the reversing camera presented very few risks beyond those that would normally be expected during reversing manoeuvres. The camera and screen were not thought to pose any additional risks in the event of a collision as the camera is external to the vehicles and does not protrude and the screen is mounted within the rear-view mirror.

There were slight concerns regarding the judgement of distance using the reversing camera. These were raised by participants and during the heuristic evaluation. Participants felt that they would quickly become accustomed to making judgements using the system. As for all of the devices studied, a period of training or familiarisation is recommended. For the reversing camera it would be most beneficial to concentrate on learning the relationship between the image and real distances during this period.

Other concerns, such as the quality of the image and the reduction of normal rear-view (due to the heavy tinting of the two-way display mirror) could be solved by using a larger dashboard mounted screen and better quality camera (providing the mounting guidelines listed in Section 6.4.6 were followed). However, as the reversing camera is designed to be used for seeing objects close to the vehicle the image quality is not as crucial as for the junction camera.

Although a wide range of products are available via the internet for retrofit to any vehicle, it may not always be possible to access and interpret detailed information about camera and display specifications. Reversing cameras may also be supplied as standard features in new vehicles or through an adaptations company and in these cases it may be difficult for the user to specify the system according to their particular requirements.

10.4.4 Device conclusions

The reversing camera has the potential to make reversing tasks easier and safer. It would be appropriate for people with restricted movement who are not confident with reversing and would benefit from an unobstructed view behind the vehicle. The view provided exceeds that of a completely unrestricted driver. However, these potential advantages produced no significant benefit in the user test. This may be due to a combination of the unfamiliarity with the aid and the test circumstances themselves.

Despite the lack of observable benefit, participant opinion was reasonably positive based on ratings made after completing the reversing and turn in the road tasks and free comments. There are very few usability or reliability issues with this device. Those that exist could be easily resolved through practice and, if desired by the user, selection of a system with a better screen and camera.
People with restricted movement and many people with no disability rely on mirrors when they undertake reversing tasks. Compared to standard mirrors alone the reversing camera is judged to have the potential to provide valuable assistance.

10.5 Visual reversing sensor

10.5.1 Ability to compensate for the impairment

The field of view measurements showed that the detection range of the reversing sensors covers the area directly behind the vehicle up to a distance of approximately two metres. This seems limited; however, the system is designed to alert the driver to unseen objects close to the vehicle during low speed reversing manoeuvres\textsuperscript{17}. When compared to the restricted field of view plot, the reversing sensor provided detection of much lower objects than can be seen by the driver and therefore has the potential to provide benefit in the way it was designed.

The visual reversing sensor was assessed during user testing using the reverse parking and turn in the road tasks. Results for these tasks did not show any benefit of the visual reversing sensor in terms of the number of critical exceedances during reverse parking, the quality ratings of the parking or awareness of external events during the turn in the road task for either group of participants. The only significant difference in terms of task performance between the visual reversing sensor and the restricted without devices condition was that it took both artificially restricted and validation participants longer to complete the tasks.

The visual reversing sensor was not judged by either group of participants to make the reverse parking task easier or to give them more confidence. Artificially restricted participants also saw no benefit or disadvantage to the visual reversing sensor in this respect during the turn in the road task. Validation participants rated ease of task and confidence significantly lower when using the visual reversing sensor than when they had no reversing aids which suggests that it actually made the task more difficult for them. However, their scores for confidence and ease of the task were quite high even with no devices to aid them. The potential of the device to aid with reversing may have been limited by the usability issues described in the following sections (10.5.2 and 10.5.3).

10.5.2 Participant opinions

Ratings for the helpfulness of the visual reversing sensor on both tests and for both groups were around the mid point of the scale on average which suggests that the drivers found it neither particularly helpful nor particularly unhelpful.

Participant comments were a mixture of positive and negative. One particular issue raised by participants was that the lights appeared to be unreliable and did not come on when participants expected them to. This issue was more widely mentioned during the user test of the visual reversing sensor than the audible reversing sensor even though the two systems use the same set of sensors. It is possible that this difference in perception is due to the lights being inconspicuous and that some of the occasions where participants felt that the alert was not provided they may not have seen it. Some participants also found the signals difficult to interpret though the positional information provided by the lights were thought to be useful by some participants.

\textsuperscript{17} Prototype high speed reversing devices do exist.
10.5.3 Risks in use

The inconspicuousness of the lights was found to be a significant problem that limited the efficacy of the device as a reversing aid. The lights were not sufficiently bright to alert the driver if their attention was elsewhere and therefore required continuous monitoring if they were to be used. The risk of this is that the driver may be distracted from other salient information, such as other vehicles approaching, and this has a safety implication.

This problem could be eliminated using an alternative display design. For example, the lights could be made brighter and more alerting and placed in a position closer to where the driver’s attention is likely to be, such as on the door mirrors. This would still allow positional information to be conveyed and the appropriate side could light up according to where the obstacle was located. Many visual reversing sensor products are available and some of these may have a better design. Alternatively, this particular problem would not be evident if an audible alert was used; such a device is discussed in the following section.

As the lights are not attracting attention they cannot be relied upon as a warning against unexpected hazards behind the vehicle. Results of the user testing and field of view measurements suggest that there may be some unreliability and inconsistency in the detection (e.g. the field of view plot does not show a coherent pattern of detection of different test objects). There is a risk of over-reliance on such a device if users have inappropriate understanding of the device capabilities. Users should be made aware of these limitations and be advised to use the device accordingly, e.g. continue to monitor outside the vehicle for unexpected hazards and make manoeuvres slowly. None of the devices evaluated were provided with supporting information (e.g. a user manual) or packaging and this may be an appropriate vehicle for dissemination of this advice.

The visual reversing sensor did not pose any additional risks in the event of an accident.

10.5.4 Device conclusions

The sensing capability of the system has the potential to provide benefit to drivers who have restricted movement if their key concern is the risk of collision with unseen objects close to the vehicle during low speed manoeuvres. However, the potential benefit of the system was not realised during a task-based user evaluation. In particular, there was no reduction in the number of cones hit which is the type of incident the device is specifically designed to reduce.

This could be due to weakness in the design of the particular product studied and driver unfamiliarity with the device. Alternative products are available that may feature better display systems. Users may benefit from information on what characteristics to look for, as this market contains many products that may potentially confuse the driver.

There are also several limitations to the device capabilities and if users do not properly understand them there is a risk of over-reliance on the system. Users may benefit from advice on appropriate caution when using the visual reversing sensors in order to avoid becoming over reliant on the warning given.
10.6 Audible reversing sensor

10.6.1 Ability to compensate for impairment

The audible reversing sensor uses the same sensors as the visual reversing sensor and therefore has the same potential to provide benefit to drivers. It provided no significant benefit or disbenefit to either group of drivers during either the reverse park or turn in the road tasks in comparison to having no aids when restricted.

10.6.2 Participant opinions

The audible sensor was the highest rated by artificially restricted participant of all the reversing aids for use during the reverse park task (measures of helpfulness, ease of use and reliance on the device) and ratings were moderately positive. It was also rated very highly by the validation participants. Ratings given in the turn in the road task for helpfulness were also positive but not as strongly as for reverse parking so perhaps the device was not as helpful in this scenario. It was thought to be useful as attention could remain focussed on the mirrors and outside the vehicle.

Participants felt that the biggest weakness of the audible reversing sensors was that the alert did not indicate where the object was located in relation to the vehicle and this did not allow correction. The device could perhaps be combined with a visual display (e.g. similar to the visual reversing sensor or the reversing camera) to provide the most useful mix of functions.

10.6.3 Key risks in use

The interpretation of the different tones in terms of actual distance to obstacles needs to be considered in order for the device to be useful. This could be helped by a user manual which describes the sensing range of the system and the zones associated with different tones or through training/familiarisation. It was identified in the heuristic evaluation and mentioned previously in relation to the visual display for the reversing sensors that the system has a tendency to provide slightly unreliable warnings in that “false alarms” are occasionally produced. There are also the same problems with risk of over trusting the system which could be addressed through the user being aware of the limitations and using in combination with a visual display, e.g. the visual reversing sensors or reversing camera.

10.6.4 Device conclusions

The conclusions for the audible reversing sensors are the same as for the visual reversing sensors, but with less usability problems. It may also be appropriate to use the systems together to provide additional useful information to help interpret the signals. The audible feedback system may also benefit from having the ability to adjust the volume and pitch of the signal.

10.7 Panoramic mirror

10.7.1 Ability to compensate for impairment

The field of vision measurements showed that, although the mirrors provided a wide view, there were significant blind spots and low objects could not be seen. The effectiveness of the mirror was also affected by the sitting position such that those with a lower stature could see less. As such, the device may be useful for providing enhanced general awareness of traffic around the vehicle but it is unlikely to be useful for reversing tasks where vision of low objects is most beneficial.
During both the reverse parking and turn in the road tasks, the panoramic mirror provided no significant benefit or disbenefit for any measure. Both groups of participants found the turn in the road task significantly more difficult with the panoramic mirror than without and the validation participants rated the reverse park more difficult when using the panoramic mirror and it took them slightly but significantly longer to complete the task.

### 10.7.2 Participant opinions

Ratings made by both groups for helpfulness, ease of use and reliance on the device during the reverse park were very low. The panoramic mirror was not thought to be beneficial for reversing as the view provided did not go low enough. Participants also criticised the mirror for distortion of the image, distraction due to irrelevant information and obstruction of normal forward vision.

When the panoramic mirror was tested as an aid for viewing the blind spot, participants rated it marginally higher (although non-significant) than when restricted with no aids. It was preferred over the blind spot mirrors for this purpose. It was also found to be commonly used and valued among the user survey participants.

### 10.7.3 Key risks in use

The panoramic mirror was assessed as more likely to be hit by a vehicle occupant during a collision due to its size relative to a standard rear view mirror, thereby creating additional risk. However, the mirror was made of lightweight materials and would be unlikely to cause serious injury. The distortion created by the shape of the mirror, the irrelevant information shown in the view and the distraction caused to the driver could also negatively affect safety. The obscuration to the forward view for the driver was also an issue.

### 10.7.4 Device conclusions

Although the panoramic mirror was found to be the most popular device used by those with restricted neck/trunk movement, there are some concerns raised by this evaluation. It was assessed as being more likely to be contacted by a vehicle occupant during a collision due to its size. The height of the driver also greatly influences the effectiveness of the device as well as it being useful for more general observations around the vehicle rather than specific tasks such as reverse parking or turning in the road. The irrelevant information provided in the view could distract the driver. In addition, it was thought to reduce the normal rear view provided. These issues, as well as the distortion could be addressed through training or familiarisation so their impact is lessened. Design improvements could be made so that the normal rear view mirror remains and additional views are provided by attaching mirrors on hinges to the side.

### 10.8 Blind spot mirror

#### 10.8.1 Ability to compensate for impairment

It is worth noting that a blind spot when changing lanes is not specific to those with restricted neck/trunk movement and that the blind spot mirrors therefore could potentially compensate for this situation for all drivers. The view provided by the blind spot mirrors were not found to be dependent on the height of the driver, and provided a range of vision extending a long way backwards (but not out to the side). No objective measurements were possible in the user testing so the blind spot mirror was assessed by subjective ratings. It was found to produce no significant benefit for observing an overtaking vehicle and in fact, received slightly less positive ratings than having no aids for most measures. The panoramic mirror was rated better than the blind spot mirror for most measures and was considered to be significantly more helpful for the task of observing an overtaking vehicle.
10.8.2 **Participant opinions**
Participants in both groups were critical of the blind spot mirrors. They reported distortion of the image as well as difficulties judging speed and distance.

10.8.3 **Risks in use**
The slightly distorted image could place additional visual demands on the driver as the view provided is wide in a small space. Differences in the shape of blind spot mirrors available may affect the level of distortion, with flat surfaces being better than round. Due to their placement over the existing door mirror, they also create an additional blind spot in themselves.

Interpretation of the view shown could also be problematic as it could be difficult to understand what area the image is showing. Use of blind spot mirrors may also engender a false sense of security as they do not cover all blind spots as may be assumed. No additional danger would be presented to either the driver or pedestrian by using blind spot mirrors.

10.8.4 **Device conclusions**
The blind spot mirrors have potential to assist drivers, but caution is needed to ensure that they are aware of the limitations as well how to interpret what area is displayed on the mirror. Although they were not a popular device, they may be better liked if their purpose is understood, i.e. for limited range close to the vehicle extending out to the sides of the image shown in the door mirrors.

The mirrors are easy to install but can lack durability. It is also difficult to carry out fine adjustments, which may be necessary with different drivers (although the view is not dependent on the height of the driver). Awareness is needed to ensure that their placement is considered carefully. Fitting should avoid creating another blind spot and ensure an optimal view which does not overlap with the view provided by the door mirrors and so there is no gap.

10.9 **Overall limitations of this research**
There were some limitations to this research which should be noted:

1. The review of available devices was necessarily carried out at the start of the project and therefore there may potentially have been further devices or development in current devices which were not incorporated as part of the research.
2. Only one version of each device was evaluated in depth, as it was not feasible to assess further variations. Where possible, comments have been made about how the findings might generalise to other examples of the devices. Some findings, particularly those relating to usability issues may only be relevant to the particular devices studied.
3. The majority of the participants in the user testing phase were unfamiliar with the devices and vehicle. Familiarisation sessions were provided. However, problems which would be overcome with practice over time are potentially over-represented in the findings. This applies in particular to issues such as the judgement of distance.
4. For safety reasons, the user testing did not involve any interaction with other road users. Therefore, any issues related to use of devices in traffic could not be fully considered. This limitation has most impact on findings relating to junction view devices as they are designed for a situation where interaction with other road users is a crucial element.
11 Recommendations

11.1 Use of the devices

Based on the results of the user survey and user testing it appears that the situation where a driver would need to rely totally on an observation aid is rare. Drivers with restricted neck or trunk movement who would consider the use of aids may do so in order to increase comfort and confidence and perhaps to reduce fatigue. Reversing and viewing the vehicle’s blind spot when restricted were not found to be particularly problematic during the user testing.

Drivers choosing to use such systems would still be responsible for ensuring their own safety and that of others. This is no different from the responsibility of any licensed driver using additional equipment in the vehicle. Users should be reminded of this responsibility when they begin to use any new observation aid.

If drivers are to rely totally on any observation aid then they should only do so if the design of the aid has been inspected for safety at an appropriate level and if they have undertaken suitable familiarisation and/or training.

None of the devices offered the restricted driver benefits equal to those of the unrestricted driver. There was also a question with the junction view devices over whether they were appropriate for use in high speed situations. This question could not be properly assessed as part of the current research. Design improvements could be made to the junction camera system which would increase its efficacy as an aid in higher speed situations (see Section 11.4). Training is also recommended to address this limitation although this should only be used to supplement appropriate design and not compensate for poorly designed systems.

Camera based systems were of particular concern among the project stakeholders. Based on the evidence from the user trial, camera based systems can offer equal or greater benefit than mirrors for reversing and making observations at junctions and should therefore be considered as an alternative option. However, the design limitations of the particular junction camera system studied have a bearing on this conclusion. It is recommended that the fundamental design flaws are addressed and the device is re-examined before the system is considered acceptable (see Section 11.4).

11.2 Provision of information to users

Results of the user survey and consultation indicated a lack of clarity in the current situation. Drivers with restricted neck or trunk movement would benefit from greater access to information in several areas.

Firstly, drivers would benefit from clarification regarding where and in what circumstances they should seek advice on driving with restricted movement.

If drivers are to consider using an observation aid, careful selection of an appropriate product is essential. Up-to-date and independent information to help users choose an appropriate device would have a positive impact. The information should include descriptions of the different observation aids available as well as information on practical issues such as:

- What tasks different devices are suitable/not suitable for
• Approximate cost of devices
• Installation requirements
• Where they can be purchased
• Whether training is recommended and where to obtain it

Finally, drivers with restricted movement should be made aware of their legal and/or administrative obligations regarding who should be informed about their restriction(s). Any requirements should be clear and relatively easy for the individual to satisfy. In particular, drivers should be aware of the circumstances in which they should inform the DVLA and their insurance company.

11.3 Training

Having purchased an observation aid, training or guidance should be provided to ensure that it can be used safely. The level of training required should be appropriate for the level of risk posed from failure to use the device properly and the magnitude of the change in the driving task caused by using the aid. For example, a more complex device such as a junction camera system is likely to require far more training than a panoramic mirror.

At the least, information should always be provided to the user at the point of purchase. This may simply be in the form of a user manual or through instruction from the installer. It should include intended use and limitations, acknowledgement of the driver’s responsibility, instructions on how to set-up or install the device (if not professionally installed), how to adjust it appropriately and how to use the features.

If provided, training should particularly focus on the following areas:
• Familiarisation with the device to allow accurate distance judgements
• Familiarisation with the device to allow accurate speed/time to collision judgements
• Information about how a driver might behaviourally adapt to the device and what strategies could be used to maximise safety
• The limitations of the device, such as, the limit of view/detection/sensing range (including blind spots); the likelihood of false alarms and factors that may affect reliability.

The level of risk associated with the use of junction view devices and the impact their use has on the driving task dictate that drivers relying on these devices should undertake proper supervised instruction in a dual control vehicle in real traffic.

11.4 Device design

A number of design limitations were identified during the evaluation. In the main, these issues were minor in nature and would represent inconvenience to the driver or would result in them taking longer to get used to the system. However, the issue regarding the junction camera system and the likelihood that drivers will mistake the view they are looking at is serious and should be addressed before any such system is deemed acceptable.
Junction camera systems (or any camera system capable of showing more than one view) should clearly and unmistakeably inform the driver what view is displayed at a given time. Ideally, this information would be location coded rather than simply text based (e.g. the left view displayed on the left of the screen or to the left of a diagram of the vehicle) to conform to their pre-existing expectations as this information needs to be quickly assimilated.

Table 10 summarises the design recommendations made regarding the particular devices studied.

Table 10 – Recommendations for improved design of systems studied

<table>
<thead>
<tr>
<th>Device</th>
<th>Design recommendations</th>
</tr>
</thead>
</table>
| Junction camera   | • Ensure compatibility between controls and control output (i.e. button on left activates left camera view)  
                     • Provide clear and unmistakeable feedback regarding what camera view is shown  
                     • Increase quality of camera to provide a more clear and more distant view  
                     • Use bespoke specification to ensure greatest benefit for the individual user  
                     • If possible, display using a larger dashboard mounted screen (following best practice described in section 6.4.6) |
| Gooseneck mirror | • Use alternate fixing mechanism and/or longer “neck” to maximise positioning opportunities in order to avoid obstruction by the A pillars |
| Reversing camera | • If possible, display using a larger dashboard mounted screen (following best practice described in section 6.4.6) |
| Visual reversing sensors | • Make visual alert more conspicuous and/or combine with alerting stimulus such as a tone |
| Audible reversing sensors | • Provide additional positional information to help users identify obstructions |
| Blind spot mirror | • Avoid positioning on the face of the door mirrors as this creates a blind spot |

Generally, the design of all in-vehicle equipment, including driver assistance systems, should follow ergonomic good practice. This guidance is widely available, although not always in an easily accessible format for the purposes of designers and manufacturers. It may be appropriate to consider the development of specific best practice guidance for use in the development of technology for disabled people as this seems to be an area where ergonomic best practice is currently lacking. Such a guide could perhaps be used as a voluntary code of practice by manufacturers and installers. Individuals and mobility services could use this as a criterion to distinguish between alternative products.

The installation of driver aids should also always take into account the safety of the vehicle occupants and pedestrians in a crash situation. Where possible, equipment should not be placed in a position where it may be struck by occupants and/or pedestrians; should not pose a
risk of serious injury if struck (e.g. by having sharp edges) and should not impair or prevent
the use of other vehicle safety equipment such as airbags. Guidelines to this effect could also
be included in a best practice guide for manufacturers and installers.

Finally, systems that are manually activated by the user in addition to the normal driving task
(e.g. pressing a button to activate the junction camera) may be difficult to use with other
adaptations, such as hand controls. In this situation, a bespoke design and installation would
be recommended to ensure that the aid can be easily used and is appropriate for the individual.

11.5 Licensing policy

The requirements for licensing drivers with restricted movement who need to rely on an
observation aid are currently both confusing and incomplete. Only modified rear-view is
catered for and this does not cover junction view systems. In the rare situation that drivers
need to rely totally on a piece of equipment to drive then it seems appropriate that the DVLA
be aware of this requirement and that it is acknowledged on the individual’s licence.

However, the criteria for determining whether people need to rely on an observation aid are
not defined. Further work to determine an appropriate assessment method and boundary for
making these judgements is recommended.

12 References

relating to the rear view mirrors of motor vehicles. Office for Official Publications of the
European Communities

American Association of State Highway & Trans; Metric edition

reversing motor vehicles*. NSW Motor Accidents Authority


McGraw-Hill International Editions

Acknowledgements

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installation.
## Appendix A: List of manufacturers or adaptation specialists

<table>
<thead>
<tr>
<th>Manufacturer/Specialist</th>
<th>Website/Contact Number</th>
<th>Types of Product Made/Supplied</th>
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<tr>
<td>AKRO</td>
<td><a href="http://www.perfparking.co.uk">www.perfparking.co.uk</a></td>
<td>Parking Sensors</td>
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<td>Auto-Mobility Concepts Ltd</td>
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<td>Parking sensors, reversing cameras</td>
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<tr>
<td>Bern Optical Products Ltd</td>
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Appendix B. List of organisations contacted for user survey

The following organisations have all been approached in order to assist with the recruitment for the user survey (those with an asterisk have agreed in principle and those with two asterisks have already assisted):

Blue Badge Network**
Disability Now magazine**
Newcastle Mobility Centre & clinic**
Wrightington Mobility Centre**
MAVIS**
Disability Direct**
Leonard Cheshire**
Arthritis Care**
Able Magazine**
MAGIC*
Assist UK*
Mobilise Organisation*
High Wycombe Group of Advanced Motorists*
Age Concern*
GEM Motoring Assist*
Spinal Injuries Association
JMU Access Partnership
Disabled Living Foundation
National Ankylosing Spondylitis Society (NASS)
Derby Mobility Centre
Institute of Advanced Motorists
Motability
William Merritt Mobility Service
WAMSAD (Windsor, Ascot, Maidenhead District Sports Association for Disabled)
SKILL
British Polio Fellowship
SAGA
Yourable.com
Appendix C. Project advertisement for user survey

VOLUNTEERS WANTED TO PARTICIPATE IN RESEARCH STUDY: DRIVING WITH RESTRICTED NECK AND TRUNK MOVEMENT

The Transport Research Laboratory (TRL Ltd) has been commissioned by the Department for Transport to conduct an independent research study to look at the issues around use of observation devices (such as additional mirrors or video cameras) to assist drivers with restricted neck and trunk movement, for example at junctions, blind spots, and whilst reversing. If you have restricted neck or trunk function which may affect your ability to drive or for which you now have adaptations, or even if this has caused you to give up or restrict your driving, we would be grateful for up to 30 minutes of your time to discuss this over the telephone. The information collected will only be used for research purposes and may potentially inform policy regarding the use of these devices.

To volunteer or obtain more information please contact:

Rebecca Hutchins
TRL Limited
Crowthorne House
Nine Mile Ride,
Wokingham
RG40 3GA
Tel 01344 770318
Email: rhutchins@trl.co.uk
Appendix D. User survey topic guide

A. Introduction to interviewee
Thank you for agreeing to be interviewed. The interview should not take longer than 30 minutes. Is this still a convenient time for you? Please say if you need a break or do not wish to continue with the interview.

First I’ll tell you a little bit more about the project. The Department for Transport’s Mobility and Inclusion Unit has commissioned TRL Ltd to conduct a study to identify the issues surrounding the use of observation devices (such as rear view mirrors or cameras) for use by drivers with restricted neck and trunk movement. The objectives are to identify what is available, explore and report on the reliability and safety, and to make recommendations on the fitting, use, training and licensing. As part of the project we are interviewing users of devices and those who may benefit from using them.

To help us with our reporting of this interview, I would like to record what is said. The recording will be deleted at the end of the study and comments or findings will be not be attributable to a particular individual. Do you have any objections to the interview being recorded? [Note to interviewer: If interviewee has objections, explain that the interview may take a bit longer as notes will have to be made]

Do you have any questions before we begin?

B. Background
- Please can you describe the nature & extent of your medical condition or problem?
  - Restricted neck movement
  - Restricted trunk movement
  - What was the cause?
  - Receiving treatment or physiotherapy (which may affect choice of device)
- Do you have a vision impairment of any kind, such as cataracts?
- What problems do you have with being able to make observations in the vehicle?
  - Problems turning the vehicle (left or right or 3-point turn)
  - Problems reversing (in a straight line or round a corner)
  - Problems looking left or right at junctions
  - Blind spots- specify which
  - Other - specify
- How long have your observations whilst driving been affected?
- Have you notified DVLA that your driving may have been affected due to difficulties with observations?\(^{18}\)
  - In not – why?
  - If yes, what did you say and what was the outcome? Any advice offered?
- Do you still currently drive?

\(^{18}\) If interviewee seems concerned by this question, reassure them that their participation in the interview is confidential and the research is being conducted independently of DVLA. For information DVLA state that “If you have had, or currently suffer from a medical condition or disability that may affect your driving you must tell the DVLA. You’ll also need to provide details if you develop a new condition or disability or one that has become worse since your licence was issued. Failure to notify DVLA is a criminal offence and is punishable by a fine of up to £1000.”
### If NOT currently driving

- **Why don’t you currently drive?**
  - Finding it was too difficult to continue driving
    - In what way?
    - Particular situations?
  - DVLA revoked licence
  - Was recommended to stop
    - For what reason?
    - By Who? (Mobility Centre, GP, family/friends)
  - Financial issues (cost of adaptations)?
  - Accident/incident (related to observation difficulties?)

- **When did you stop driving?**

- **Did you previously have vehicle adaptations to help you to make observations?**
  **If YES, go to C**
  **If NO...**

- **What type of adaptation to assist with your observations do you think may assist you to drive again?** [Go to G]

### If currently driving

- **What type of vehicle do you drive (manual or automatic gear transmission)?**
  - What considerations were made when purchasing (i.e. with observation difficulties in mind)?

- **How far do you drive in an average week and how often?**
  - What type of driving do you do (i.e. length of journey, number of journeys, drive for work)

- **How have you changed your driving habits due to difficulties with observations?**
  - Reduced total mileage, length of journeys, when/where drive
  - Edge out slowly at junctions/take longer
  - Ask someone in car (or outside if parking) for advice
  - Take a chance
  - Avoid certain manoeuvres

- **Can you recall any accidents/incidents which may be related to difficulties with observations?**

- **Do you currently use any type of car adaptations?**
  **If YES, go to Section C - allow interviewee to mention ALL adaptations but focus on adaptations to assist with restricted neck/trunk movement**
  **If NO...** What type of vehicle adaptation to help with your observations do you think may assist you to drive more safely or comfortably? Awareness & knowledge of devices (advice/cost/installation) [Go to G]
C. Purchase and installation

- What type of adaptation do/did you use to assist with observation due to restricted neck/trunk movement?
  - Panoramic/rear view mirror
  - Video cameras
  - Blind spot mirror
  - Reversing aids (specify which type, e.g. sensors)
  - Other
- Are there specific factory fitted features in your vehicle that you chose to help with observations because of your restricted neck/trunk movement?
- Where did you purchase the device – how did you hear about it and why did you chose this device over another one?
- How was it funded and what is your opinion of the price?
  - How much cost to fit?
  - How much cost to upkeep?
  - Motability funding?
- Can you tell me about the installation of the observation device in your car?
  - When was it installed?
  - Who fitted the device? (adaptations specialists, regular garage, yourself)
  - Time (from purchase to fitting to using unassisted)
  - Cost to fit
  - Any advice given and what
  - Upkeep/running costs
  - Difficulties in fitting (complicated) or finding someone to fit it
- How easy or difficult is the observation device to remove?
  - On what occasions is it removed (someone else wants to drive the car)?
  - Affect on insurance?
  - Are there any other issues related to other people using the device?

D. Advice and Notification [for each device used or tried]

- Did you inform the DVLA that you were using the observation device?
  - In not – why?
  - If yes - what did you say, did they offer any advice, what was the outcome?
- Did you inform your insurance company?
  - In not – why?
  - If yes - what did you say, did they offer any advice, what was the outcome?
- What advice did you receive about observation devices before being fitted?
  - Where to find devices and who to purchase from
  - How to fit and who would fit
  - How to use
  - Who from? (manufacturer, Mobility Centre, GP, DVLA, insurers)
  - How useful was it?
  - Any other legal constraints

E. Use and Reliability

- In what situations do/did you use the observation device?
  - Only when driving on motorways/at high speeds
  - Only when driving alone/rely on someone else when in the vehicle
  - Poor weather conditions
  - When dark/poor visibility
  - When roads are busy
  - When more affected by functional impairment (i.e. condition changes)
• How do the observation devices help you with your driving/manoeuvres?
  o To observe at junctions – what type?
  o To reverse round a corner or in a straight line
  o Changing lanes
  o Merging with traffic
• How often do/did you use the observation device when driving?
  o Every time in certain manoeuvre/unable to drive without
  o When having difficulties (as a last resort)
• Where did you learn about how to use the observation device/did you receive any training?
  o By yourself
  o Device or manufacturers manual
  o Mobility Centre
  o Motability
  o Adaptation specialist
• How easy or difficult is the observation device to operate?
  o Specific situations or examples where difficulties
  o Accessing the information, e.g. if using a camera, how change screens?
  o Ways to improve device?
• Do you have any concerns over the use of the device?
  o Speed/distance judgements difficult with cameras
  o Over-sensitive reversing sensors
  o Distortion of mirrors
  o Trust issues - time spent looking at/using device rather than road ahead
• Are there any issues related to the reliability of the observation device?
  o Situations where let down by device, when, broken down ever?

F. Safety/compensation for impairment
• What affect do you think the observation device has had on your ability to drive? Long or short term differences (i.e. driving style, learning time)
• How has the device enabled you to drive more safely?
• Are there any situations in which the device does not assist or is of no benefit?
• Can you recall any incidents/accidents which may be related to its use?
• In comparison to the time before you had the device installed, how safe do you feel driving with the device (any incidents/accidents before)?

G. User testing
• Thank you for taking part in this interview. We are nearing the end of the interview now, so do you have anything you would like to add? [If ask about results of project say that it should be published May 2007, add name to list]
• [If current driver with license & quite local to TRL] As part of this project we will also be carrying out some user trials in order to test the technology available. Would you be willing to participate in these trials at Crowthorne towards the end of this year? It is likely to involve a whole day and financial compensation would be made for your time and travel expenses.
• Can we keep your details on record for future research projects?

END OF INTERVIEW
## Appendix E. Volunteer characteristics

<table>
<thead>
<tr>
<th>Driving status</th>
<th>Devices used</th>
<th>Medical condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently driving</td>
<td>None</td>
<td>Ankylosing Spondylitis (AS) and Scheuermann’s AS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spina bifida and Scoliosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scoliosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arthritis and psoriasis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arthritis, whiplash injury and trapped nerve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arthritis and whiplash injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whiplash injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prolapsed discs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prolapsed disc and osteoporosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broken back in three places</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broken neck in three places</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paraplegic (spinal cord injury)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tetraplegic spinal cord injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Injuries to soft tissue of neck</td>
</tr>
<tr>
<td>Panoramic rear view</td>
<td>Panoramic rear view mirror only</td>
<td>Arthritis and crumbling bones</td>
</tr>
<tr>
<td>mirror only</td>
<td></td>
<td>Spina bifida</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial paralysis</td>
</tr>
<tr>
<td>Panoramic rear view</td>
<td>Panoramic rear view mirror and blind spot mirrors on door mirror</td>
<td>Cerebral Palsy</td>
</tr>
<tr>
<td>mirror and blind spot</td>
<td></td>
<td>Partial paralysis</td>
</tr>
<tr>
<td>mirrors on door mirror</td>
<td></td>
<td>Stiffness in trunk/neck due to old age</td>
</tr>
<tr>
<td>Panoramic rear view</td>
<td>Panoramic rear view mirror and internal blind spot mirrors</td>
<td>Arthritis</td>
</tr>
<tr>
<td>mirror and internal</td>
<td></td>
<td>Osteoarthritis, scoliosis, dystonia</td>
</tr>
<tr>
<td>spot mirrors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Reversing camera</td>
<td>AS</td>
</tr>
<tr>
<td>Self-made mirror on</td>
<td>Self-made mirror on dashboard with adjustable ball and socket joint</td>
<td>Scoliosis and AS</td>
</tr>
<tr>
<td>dashboard with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>adjustable ball and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>socket joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panoramic mirror and</td>
<td>Panoramic mirror and reversing lens</td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td>reversing lens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panoramic rear view</td>
<td>Panoramic rear view mirror, reversing lens, mirrors on swivel joints on rear</td>
<td>AS</td>
</tr>
<tr>
<td>mirror, reversing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>view, mirrors on swivel joints on rear view, and mirror on sun visor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feature/Condition</td>
<td>Details</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Panoramic rear view mirror, blind spot mirrors, reversing lens, and manufacturer-fitted audible reversing sensors</td>
<td>Scoliosis</td>
<td></td>
</tr>
<tr>
<td>Panoramic mirror and retro-fitted audible reversing sensors</td>
<td>Osteoarthritis and slipped disc</td>
<td></td>
</tr>
<tr>
<td>Blind spot mirror on dashboard</td>
<td>Rheumatoid arthritis</td>
<td></td>
</tr>
<tr>
<td>Blind spot mirrors on door mirrors only</td>
<td>Degenerative calcification of the neck</td>
<td></td>
</tr>
<tr>
<td>Factory-fitted auditory reversing sensors</td>
<td>Spinal injury to neck in three places</td>
<td></td>
</tr>
<tr>
<td>Retro-fitted reversing sensors</td>
<td>Damaged vertebrae in neck</td>
<td></td>
</tr>
<tr>
<td>Learning to drive</td>
<td>Panoramic rear view mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spina bifida</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arthritis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polio</td>
<td></td>
</tr>
<tr>
<td>Stopped driving</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arthritis and damage to C2-5 vertebrae and slipped discs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forestier’s Disease</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cerebral Palsy</td>
<td></td>
</tr>
</tbody>
</table>
Appendix F. Map of TRL’s Small Road System
Appendix G. Procedures and instructions given to participants

Reverse parking

Procedure

1. Park vehicle at specified starting point
2. R1 sets up relevant device for condition:
   a. Ensure that the visual reversing sensor is covered when it is not being tested
   b. Switch off the reversing camera when not being tested
   c. Remove the panoramic mirror when testing other devices
   d. Switch of audible function of reversing sensor when not being tested
3. Participant takes driving seat, fits neck brace (if required) and seatbelt
4. R1 gives demonstration of the relevant device and task instructions for practice session
5. Participant does practice
6. Return to starting point
7. R1 gives instructions for experimental session
8. When ready participant does experimental reverse parking task, R2 collects objective measures
9. R1 collects subjective measures
10. Return to starting point and repeat for next condition

Instructions for main trials

When waiting at the specified starting point:

Unrestricted condition:

Practice: We will do one practice before we record the results to allow you to get used to the task. I would like you to reverse park into the space marked by four cones. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. The results for this will not be recorded. Please start when you are ready and when you have finished please drive the vehicle back to this starting point. You may use all of your normal mirrors for this task. For all future reverse parks, please approach from the same direction.

Experimental: For your next attempt we will record the results. We will be recording both time taken and the accuracy of the parking. When ready please reverse park into the space marked by four cones. When you have finished please signal by sounding the horn.

Restricted condition:

Practice: We will do one practice before we record the results to allow you to get used to the task. I would like you to reverse park into the space marked by four cones. The results for this will not be recorded. Please keep your back against the seat, your head against the headrest and your seatbelt on during this task. Start when you are ready and when you have finished please drive the vehicle back to this starting point. Again, you may use all of your normal mirrors for this task.

Experimental: For your next attempt we will record the results. We will be recording both time taken and the accuracy of the parking. Please keep your back against the seat your head against the headrest and your seatbelt on during this task during this task. When ready please reverse park into the space marked by four cones. When you have finished please signal by sounding the horn.
Device condition:

**Practice:** We will do one practice before we record the results to allow you to get used to using the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. I would like you to reverse park into the space marked by four cones. Please keep your back against the seat during this task. The results for this will not be recorded. Start when you are ready and when you have finished please drive the vehicle back to this starting point. You may still use all of your normal mirrors for this task.

**Experimental:** For your next attempt we will record the results. We will be recording both time taken and the accuracy of the parking. Please use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Please keep your back against the seat your head against the headrest and your seatbelt on during this task during this task. When ready please reverse park into the space marked by four cones. When you have finished please signal by sounding the horn.

Instructions for validation phase

When waiting at the specified starting point:

**Without devices condition:**

**Practice:** We will do one practice before we record the results to allow you to get used to the task. I would like you to reverse park into the space marked by four cones. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. The results for this will not be recorded. Please start when you are ready and when you have finished drive the vehicle back to this starting point. You may use all of your normal mirrors for this task. For all future reverse parks, please approach from the same direction.

**Experimental:** For your next attempt we will record the results. We will be recording both time taken and the accuracy of the parking. When ready please reverse park into the space marked by four cones. When you have finished please signal by sounding the horn.

**With devices condition:**

**Practice:** We will do one practice before we record the results to allow you to get used to using the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. I would like you to reverse park into the space marked by four cones. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. The results for this will not be recorded. Start when you are ready and when you have finished please drive the vehicle back to this starting point. You may still use all of your normal mirrors for this task.

**Experimental:** For your next attempt we will record the results. We will be recording both time taken and the accuracy of the parking. Please use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Please keep your seatbelt on during this task during this task. When ready please reverse park into the space marked by four cones. When you have finished please signal by sounding the horn.
Blind spot task

Procedure

1. Park vehicle at specified starting point (Silverleaf drive-1)
2. R1 sets up observation aid (if appropriate):
   a. Ensure that the blind spot mirrors are removed when not being tested
   b. Remove the panoramic mirror when testing other devices
3. Participant takes driving seat, fits neck brace (if required) and seatbelt
4. R1 gives participant instructions
5. R1 Signals to R2 that they are ready to approach
6. Participant observes stimulus vehicle
7. R1 collects subjective ratings
8. Repeat for next permutation

Instructions for main trials

When waiting in the designated starting place

Unrestricted condition: Please imagine that you are travelling in the left lane of a dual carriageway and are planning to move into the right lane. A car will shortly approach you from behind. When you see it approaching please observe it as well as you can. You may move or turn in your seat to get a better view but you must keep your seatbelt on.

Restricted condition: Please imagine that you are travelling in the left lane of a dual carriageway and are planning to move into the right lane. A car will shortly approach you from behind. When you see it approaching please observe it as well as you can. You may use all of the normal mirrors to make your observations but please keep your back against the seat, your head against the headrest and your seatbelt on.

Device condition: Please imagine that you are travelling in the left lane of a dual carriageway and are planning to move into the right lane. A car will shortly approach you from behind. When you see it approaching please observe it as well as you can. You may use all of the normal mirrors and the additional panoramic/blind spot mirror to make your observations but please keep your back against the seat, your head against the headrest and your seatbelt on.

Instructions for validation trials

When waiting in the designated starting place

Without devices condition: Please imagine that you are travelling in the left lane of a dual carriageway and are planning to move into the right lane. A car will shortly approach you from behind. When you see it approaching please observe it as well as you can. You may use all of the normal mirrors to make your observations. You may move or turn in your seat to get a better view but you must keep your seatbelt on.

With devices condition: Please imagine that you are travelling in the left lane of a dual carriageway and are planning to move into the right lane. A car will shortly approach you from behind. When you see it approaching please observe it as well as you can. You may use all of the normal mirrors and the additional panoramic/blind spot mirror to make your observations. You may also move or turn in your seat to get a better view but you must keep your seatbelt on.
# Turn in the road

## Procedure

1. Park vehicle at specified starting point
2. R1 sets up relevant device for condition:
   - a. Ensure that the visual reversing sensor is covered when it is not being tested
   - b. Switch off the reversing camera when not being tested
   - c. Remove the panoramic mirror when testing other devices
   - d. Switch of audible function of reversing sensor when not being tested
3. Participant takes driving seat, fits neck brace (if required) and seatbelt
4. R1 gives demonstration of the relevant device and practice instructions
5. Participant does practice and returns to starting point
6. R1 gives experimental instructions
7. When ready, participant does reverse park task, R2 collects objective measures
8. R1 collects subjective measures and counts the number of flashes seen by the participant
9. Return to starting point and repeat for next condition

## Instructions for main trials

*When waiting at the specified starting point:*

**Unrestricted condition:**

*Practice:* We will do one practice before we record the results to allow you to get used to the task. Starting from this point I would like you to make a turn in the road so that you finish at the marker on the other side of the road ready to proceed in the other direction. The two other vehicles will flash their lights intermittently; please say ‘now’ when you see the lights flash. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. Please try to avoid hitting the kerb. Please start when you are ready and when you have finished please drive the vehicle back to this starting point. The results for this will not be recorded.

*Experimental:* For your next attempt we will record the results. We will be recording both time taken and the accuracy of the turn in the road. As before, try to avoid hitting the kerb. When ready make your turn in the road so that you finish by the marker on the other side of the road.

**Restricted condition:**

*Practice:* We will do one practice before we record the results to allow you to get used to the task. Starting from this point I would like you to make a turn in the road so that you finish at the marker on the other side of the road ready to proceed in the other direction. Again, the two other vehicles will flash their lights intermittently; please say ‘now’ when you see the lights flash. Please try to avoid hitting the kerb. Please keep your back against the seat, your head against the headrest and your seatbelt on during this task. Please start when you are ready and when you have finished please drive the vehicle back to this starting point. The results for this will not be recorded.

*Experimental:* For your next attempt we will record the results. We will be recording both time taken and the accuracy of the turn in the road. As before, try to avoid hitting the kerb. Please keep your back against the seat during this task your head against the headrest and your seatbelt on. When ready make your turn in the road so that you finish by the marker on the other side of the road.
Device condition:

Practice: We will do one practice before we record the results to allow you to get used to the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Starting from this point I would like you to make a turn in the road so that you finish at the marker on the other side of the road ready to proceed in the other direction. Again, the two other vehicles will flash their lights intermittently; please say ‘now’ when you see the lights flash. Please try to avoid hitting the kerb. Please keep your back against the seat, your head against the headrest and your seatbelt on and use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Please start when you are ready and when you have finished please drive the vehicle back to this starting point. The results for this will not be recorded.

Experimental: For your next attempt we will record the results. We will be recording both time taken and the accuracy of the turn in the road. As before, try to avoid hitting the kerb and be aware of the possibility of other traffic. Please keep your back against the seat, your head against the headrest and your seatbelt on and use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. When ready make your turn in the road so that you finish by the marker on the other side of the road.

Instructions for validation trials

When waiting at the specified starting point:

Without devices condition:

Practice: We will do one practice before we record the results to allow you to get used to the task. Starting from this point I would like you to make a turn in the road so that you finish at the marker on the other side of the road ready to proceed in the other direction. The two other vehicles will flash their lights intermittently; please say ‘now’ when you see the lights flash. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. Please try to avoid hitting the kerb. Please start when you are ready and when you have finished drive the vehicle back to this starting point. The results for this will not be recorded.

Experimental: For your next attempt we will record the results. We will be recording both time taken and the accuracy of the turn in the road. As before, try to avoid hitting the kerb.

With devices condition:

Practice: We will do one practice before we record the results to allow you to get used to the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Starting from this point I would like you to make a turn in the road so that you finish at the marker on the other side of the road ready to proceed in the other direction. Again, the two other vehicles will flash their lights intermittently; please say ‘now’ when you see the lights flash. Please try to avoid hitting the kerb. You may move or turn in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. Use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. Please start when you are ready and when you have finished drive the vehicle back to this starting point. The results for this will not be recorded.

Experimental: For your next attempt we will record the results. We will be recording both time taken and the accuracy of the turn in the road. As before, try to avoid hitting the kerb and be aware of the possibility of other traffic. Please keep your seatbelt on and use the reversing camera/audible reversing sensor/visual reversing sensor/panoramic mirror as a reversing aid. When ready make your turn in the road so that you finish by the marker on the other side of the road.
Junction detection task

Procedure

1) R1 to drive to the junction and position the vehicle according to markers
2) Participant takes driving seat
3) Prepare for relevant condition:
   a) Ensure that the junction camera is switched off when not being tested
   b) Remove the gooseneck mirror when not being tested
4) R1 gives instructions to participants
5) R1 signals to R2 that it is ok to begin their approach
6) R2 approaches the junction from relevant direction at a speed of 5 mph
7) Participant watches and sounds horn when vehicle is seen
8) R2 immediately stops vehicle and marks position of front wheel
9) R2 measures and notes distance
10) R1 collects subjective data
11) Repeat for next approach

Note: keep same order of conditions and always start in left turn position

Instructions for main trials

Once positioned at the junction:

Unrestricted condition: A car or a bike will shortly approach from the left/right. Search for it by looking out of the windows. You may move in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. When you can first clearly see the vehicle sound the horn loudly and clearly. I am now going to signal to the driver of the other vehicle that we are ready to start.

Restricted condition: A car or a bike will shortly approach from the left/right. Search for it by looking out of the windows. You must keep your back flat against the back of the seat, your head against the headrest and your seatbelt on. When you can first clearly see the vehicle sound the horn loudly. I am now going to signal to the driver of the other vehicle that we are ready to start.

Devices condition: A car or a bike will shortly approach from the left/right. Search for it using the view provided by the junction camera/gooseneck mirror and looking out of the window. You must keep your back flat against the back of the seat, your head against the headrest and your seatbelt on. When you can first clearly see the vehicle in the junction camera/gooseneck mirror or through the window sound the horn clearly. I am now going to signal to the driver of the other vehicle that we are ready to start.

Instructions for validation trials

Once positioned at the junction:

Without devices condition: A car or a bike will shortly approach from the left/right. Search for it by looking out of the windows. You may move in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. When you can first clearly see the vehicle sound the horn loudly and clearly. I am now going to signal to the driver of the other vehicle that we are ready to start.

With devices condition: A car or a bike will shortly approach from the left/right. Search for it using the view provided by the junction camera/gooseneck mirror and looking out of the window. You may move in your seat to try and see further, as you normally would when
driving, but you must keep your seatbelt on. When you can first clearly see the vehicle in the junction camera/gooseneck mirror or through the window sound the horn clearly. I am now going to signal to the driver of the other vehicle that we are ready to start.

**Junction usability task**

**Procedure**

1. Participant stops at cone before the junction
2. R1 gives instructions and demonstration (for device conditions):
   a) *Ensure that the junction camera is switched off when not being tested*
   b) *Remove the gooseneck mirror when not being tested*
3. When ready, participant makes the manoeuvre- R2 times the whole manoeuvre from vehicle moving off to vehicle stopping. R1 observes participant using devises to see what, if any, problems are encountered
4. when stopped, R1 gives subjective measures and collects usability comments from participants
5. Return to start point (use routes described in the table below)
6. repeat for next condition

<table>
<thead>
<tr>
<th>Junction</th>
<th>Turn</th>
<th>Route</th>
</tr>
</thead>
</table>
| J6 Left  | (onto Silverleaf Drive-2) | • Take 1<sup>st</sup> left into Robertson lane  
• At the roundabout, turn left onto Bridle Hill Rise  
• Take the next left into Cornelius Avenue  
Return to start point |
| J6 Right | (onto Silverleaf Drive-2) | • Take 1<sup>st</sup> right onto Cornelius Avenue  
• Return to start point |
| J5 Left  | (onto Silverleaf Drive-2) | • Take 1<sup>st</sup> left into Charlesworth Street-1  
• At crossroads, turn left into Silverleaf Drive- 8  
• At the T junction, turn left into Robertson Lane  
• Return to start point* |
| J5 Right | (onto Silverleaf Drive-2) | • Take 1<sup>st</sup> right into Cornelius Avenue  
• Take 1<sup>st</sup> right into Bridle Hill Rise  
• At the roundabout take 3<sup>rd</sup> exit into Robertson Lane  
• Return to start point* |

**Instructions for main trials**

*When waiting before the junction:*

**Unrestricted condition:** At the junction ahead I would like you to turn right/left. Please approach the junction as you would normally, check that it is clear and make the turn. You may move in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. You should satisfy yourself completely that there is no traffic approaching and do not make the turn until you are certain. After you have made the turn bring the vehicle to a stop safely, level with the traffic cone. Carry on when you are ready.

**Restricted condition:** At the junction ahead I would like you to turn right/left. Please approach the junction as you would normally, check that it is clear and make the turn. Please
keep your back against the seat, your head against the headrest and your seatbelt on. You should satisfy yourself completely that there is no traffic approaching and do not make the turn until you are certain. After you have made the turn, bring the vehicle to a stop safely, level with the traffic cone. Carry on when you are ready.

**Device conditions:** At the junction ahead I would like you to turn right/left. Please approach the junction as you would normally, check that it is clear using the junction camera/gooseneck mirror as demonstrated and make the turn. You should satisfy yourself completely that there is no traffic approaching and do not make the turn until you are certain. Please keep your back against the seat, your head against the headrest and your seatbelt on. After you have made the turn bring the vehicle to a stop safely, level with the traffic cone. Carry on when you are ready.

**Instructions for validation trials**

*When waiting before the junction:*

**Without devices condition:** At the junction ahead I would like you to turn right/left. Please approach the junction as you would normally, check that it is clear and make the turn. You may move in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. You should satisfy yourself completely that there is no traffic approaching and do not make the turn until you are certain. After you have made the turn bring the vehicle to a stop safely, level with the traffic cone. Carry on when you are ready.

**With devices condition:** At the junction ahead I would like you to turn right/left. Please approach the junction as you would normally, check that it is clear using the junction camera/gooseneck mirror as demonstrated and make the turn. You should satisfy yourself completely that there is no traffic approaching and do not make the turn until you are certain. You may move in your seat to try and see further, as you normally would when driving, but you must keep your seatbelt on. After you have made the turn bring the vehicle to a stop safely, level with the traffic cone. Carry on when you're ready.
## Appendix H. Permutations and conditions for driving tasks

### Reversing manoeuvres conditions/permutations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permutations</th>
<th>Permutations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted (using standard mirrors)</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
<tr>
<td>Restricted (using standard mirrors)</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
<tr>
<td>Audible reversing sensor</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
<tr>
<td>Visual reversing sensor</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Practice</td>
<td>Practice</td>
</tr>
<tr>
<td></td>
<td>Reverse parking</td>
<td>Turn in the road</td>
</tr>
</tbody>
</table>

### Blind spot conditions/permutations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permutation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>On the right 10mph</td>
</tr>
<tr>
<td></td>
<td>On the right 30mph</td>
</tr>
<tr>
<td>Restricted</td>
<td>On the right 10mph</td>
</tr>
<tr>
<td></td>
<td>On the right 30mph</td>
</tr>
<tr>
<td>Blind spot mirror</td>
<td>On the right 10mph</td>
</tr>
<tr>
<td></td>
<td>On the right 30mph</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>On the right 10mph</td>
</tr>
<tr>
<td></td>
<td>On the right 30mph</td>
</tr>
</tbody>
</table>
### Junction detection conditions/permutations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permutations</th>
<th>Permutations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unrestricted condition</strong></td>
<td>J6 right position approach from right car</td>
<td>J5 approach from left car</td>
</tr>
<tr>
<td></td>
<td>J6 right position approach from right bike</td>
<td>J5 approach from left bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right car</td>
</tr>
<tr>
<td><strong>Restricted condition</strong></td>
<td>J6 right position approach from right car</td>
<td>J5 approach from left car</td>
</tr>
<tr>
<td></td>
<td>J6 right position approach from right bike</td>
<td>J5 approach from left bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right car</td>
</tr>
<tr>
<td><strong>Junction camera</strong></td>
<td>J6 right position approach from right car</td>
<td>J5 approach from left car</td>
</tr>
<tr>
<td></td>
<td>J6 right position approach from right bike</td>
<td>J5 approach from left bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right car</td>
</tr>
<tr>
<td><strong>Gooseneck mirror</strong></td>
<td>J6 right position approach from right car</td>
<td>J5 approach from left car</td>
</tr>
<tr>
<td></td>
<td>J6 right position approach from right bike</td>
<td>J5 approach from left bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right bike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J5 approach from right car</td>
</tr>
</tbody>
</table>

### Junction usability conditions/permutations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permutations</th>
<th>Permutations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Restricted</strong></td>
<td>J6 left</td>
<td>J5 left</td>
</tr>
<tr>
<td></td>
<td>J6 right</td>
<td>J5 right</td>
</tr>
<tr>
<td><strong>Unrestricted condition</strong></td>
<td>J6 left</td>
<td>J5 left</td>
</tr>
<tr>
<td></td>
<td>J6 right</td>
<td>J5 right</td>
</tr>
<tr>
<td><strong>Junction camera</strong></td>
<td>J6 left</td>
<td>J5 left</td>
</tr>
<tr>
<td></td>
<td>J6 right</td>
<td>J5 right</td>
</tr>
<tr>
<td><strong>Gooseneck mirror</strong></td>
<td>J6 left</td>
<td>J5 left</td>
</tr>
<tr>
<td></td>
<td>J6 right</td>
<td>J5 right</td>
</tr>
</tbody>
</table>
Appendix I. Detailed analysis results of user testing

1.1 Junction detection

The junction detection task collected four different measures:

- **Detection distance** – the distance of the on-coming vehicle from the junction when it was first detected by the participant

- **Ease of detection** – a subjective rating made by the participant on a 10-point scale in response to the question: “How easy or difficult was it to detect the on-coming vehicle?”

- **Clarity of view** - a subjective rating made by the participant on a 10-point scale in response to the question: “How clearly could you see and recognise the on-coming vehicle?”

- **Confidence** - a subjective rating made by the participant on a 10-point scale in response to the question: “How confident or unconfident would you feel pulling out at this junction using this observation method?”

Analysis of each measure is presented in the following sections for both the artificially restricted participants and the validation participants.

1.1.1 Detection distance – artificially restricted participants

This section describes the results of the detection distance comparison between observation conditions for the ten artificially restricted participants for each permutation studied. Unless otherwise stated, all analyses in this section were conducted using a series of Friedman tests to examine the pairs:

- Unrestricted (Unr) vs. Restricted (R)
- Unrestricted (Unr) vs. Junction camera (JC)
- Unrestricted (Unr) vs. Gooseneck mirror (GM)
- Restricted (R) vs. Junction camera (JC)
- Restricted (R) vs. Gooseneck mirror (GM)
- Junction camera (JC) vs. Gooseneck mirror (GM)

**Descriptive statistics**

Table 11 shows the mean and standard deviation of detection distance across all artificially restricted participants during each permutation of the junction detection test. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if there was an improvement (i.e. a longer detection distance) compared to the restricted condition and coloured red if there was a reduction in detection distance (i.e. if performance was worse) compared to the restricted condition. The measures are coloured blue if the difference between the restricted condition and the device condition was less than one metre. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

The descriptive statistics show that the detection distance was much higher in the unrestricted condition than in the other conditions. Detection distances in the unrestricted condition were higher at the acute angle junction compared to the 90° junction. Detection distances in the restricted condition are lower than the restricted condition for both junctions, although the effect appears to be more severe for the acute angle junction. The descriptive statistics suggest that the observation devices may have had a variable impact on the detection distances achieved. For some permutations the results in the device conditions were quite
similar or even slightly worse than the restricted condition and for others the means suggest that the devices may have given some benefit.
The variability in detection distance is quite high in the restricted, junction camera and gooseneck mirror conditions. This may have a different explanation in each condition. In the restricted condition participants may have been variable in the extent to which they moved in the seat and against the restriction provided by the neck brace and in the junction camera condition participants may have been variable in terms of their interpretation of when the oncoming vehicle was “detected”. The latter may also be true of the gooseneck mirror; additionally, the gooseneck mirror was individually adjusted by each participant.

The following sections describe the statistical testing that has been conducted on these results.
Table 11 Mean detection distances for each permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean detection distance (m) 2 d.p.</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>90° angle junction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>91.45</td>
<td>49.09</td>
<td>58.07</td>
<td>61.51</td>
</tr>
<tr>
<td></td>
<td>(±8.98)</td>
<td></td>
<td></td>
<td>(+7.18)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>8.07</td>
<td>13.43</td>
<td>17.53</td>
<td>22.41</td>
<td></td>
</tr>
<tr>
<td>Car, left approach</td>
<td>Mean</td>
<td>90.52</td>
<td>71.25</td>
<td>75.05</td>
<td>66.42</td>
</tr>
<tr>
<td></td>
<td>(±3.8)</td>
<td></td>
<td></td>
<td>(±4.83)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>14.52</td>
<td>16.25</td>
<td>9.96</td>
<td>16.16</td>
<td></td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>80.81</td>
<td>37.75</td>
<td>45.07</td>
<td>44.30 (±6.55)</td>
</tr>
<tr>
<td></td>
<td>(±7.32)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>10.81</td>
<td>24.05</td>
<td>18.23</td>
<td>19.86</td>
<td></td>
</tr>
<tr>
<td>Bike, left approach</td>
<td>Mean</td>
<td>90.90</td>
<td>67.52</td>
<td>67.86</td>
<td>58.72</td>
</tr>
<tr>
<td></td>
<td>(±0.34)</td>
<td></td>
<td></td>
<td>(±8.80)</td>
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</tr>
<tr>
<td>S.D.</td>
<td>13.32</td>
<td>18.91</td>
<td>16.09</td>
<td>27.21</td>
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</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>88.42</td>
<td>56.40</td>
<td>61.51</td>
<td>57.73</td>
</tr>
<tr>
<td></td>
<td>(±5.11)</td>
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<td></td>
<td>(±1.33)</td>
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<tr>
<td>S.D.</td>
<td>9.87</td>
<td>15.98</td>
<td>13.37</td>
<td>19.57</td>
<td></td>
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<tr>
<td><strong>Acute angle junction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>164.18</td>
<td>12.58</td>
<td>105.31</td>
<td>124.03</td>
</tr>
<tr>
<td></td>
<td>(±92.73)</td>
<td></td>
<td></td>
<td>(±111.45)</td>
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</tr>
<tr>
<td>S.D.</td>
<td>3.26</td>
<td>6.45</td>
<td>40.65</td>
<td>42.27</td>
<td></td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>163.25</td>
<td>8.56</td>
<td>48.07</td>
<td>48.65</td>
</tr>
<tr>
<td></td>
<td>(±39.51)</td>
<td></td>
<td></td>
<td>(±40.09)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>2.28</td>
<td>4.17</td>
<td>16.85</td>
<td>23.97</td>
<td></td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>163.72</td>
<td>10.57</td>
<td>76.69</td>
<td>86.34</td>
</tr>
<tr>
<td></td>
<td>(±66.12)</td>
<td></td>
<td></td>
<td>(±75.77)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>2.60</td>
<td>5.28</td>
<td>25.69</td>
<td>25.69</td>
<td></td>
</tr>
<tr>
<td>Both junctions</td>
<td>Mean</td>
<td>113.52</td>
<td>41.13</td>
<td>66.57</td>
<td>67.27</td>
</tr>
<tr>
<td>combined</td>
<td></td>
<td></td>
<td></td>
<td>(±24.44)</td>
<td>(±26.14)</td>
</tr>
<tr>
<td>S.D.</td>
<td>7.19</td>
<td>10.69</td>
<td>13.31</td>
<td>18.72</td>
<td></td>
</tr>
</tbody>
</table>

**90° angle junction, car approach from the right**

Detection distance in the unrestricted condition was significantly higher than in any other condition.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
There were no other significantly different pairs. However, the other comparisons approached significance:

- Restricted vs. Junction camera ($\chi^2 = 3.6, p = 0.058$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 3.6, p = 0.058$)
- Junction camera vs. Gooseneck mirror ($\chi^2 = 3.6, p = 0.058$)

**90° angle junction, car approach from the left**

Detection distance in the unrestricted condition was significantly higher than in any other condition.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significantly different pairs. However, the difference between the junction camera and restricted conditions approached significance ($\chi^2 = 3.6, p = 0.058$).

**90° angle junction, bike approach from the right**

Detection distance in the unrestricted condition was significantly higher than in any other condition.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significantly different pairs. However, the difference between the junction camera and restricted conditions approached significance ($\chi^2 = 3.6, p = 0.058$).

**90° angle junction, bike approach from the left**

Detection distance in the unrestricted condition was significantly higher than in any other condition.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significantly different pairs. However, the difference between the gooseneck mirror and restricted conditions approached significance ($\chi^2 = 3.6, p = 0.058$).

**90° angle junction, combined results and summary**

The detection distance results for all permutations conducted at the 90° angle junction were combined by creating an average of all detection distances within each condition. The combined variables were then subjected to the same analysis as individual permutations.

The results indicated that detection distance was significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significant differences.
At the 90° angle junction the detection distance was significantly higher in the unrestricted condition compared to the restricted condition and both device conditions for both the car and the bike and for approaches from the left and the right. The statistical tests show no significant benefit of either the junction camera or the gooseneck mirrors for this type of junction. However, several of the comparisons between the observation aids and the restricted condition neared significance.

Figure 12 shows the means for each observation condition for each permutation at the 90° angle junction. The table suggests that although there were no significant differences detected, in the case of approaches from the right the observation aids may have provided some benefit compared to the restricted condition. However, this benefit was not to the level seen when drivers were unrestricted. For approaches to the left, the gooseneck mirror was associated with a shorter detection distance compared to the restricted condition; this suggests that it may have further impaired detection.

**Acute angle junction, car approach from the right**

There was a significant difference between all pairs with the exception of the junction camera vs. gooseneck mirror.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Detection distance was significantly greater in the unrestricted condition compared to the restricted condition. The junction camera and the gooseneck mirror both significantly improved detection distance of the car approaching from the right. However, these ratings were significantly lower than those given in the unrestricted condition.

**Acute angle junction, bike approach from the right**

There was a significant difference between all pairs with the exception of the junction camera vs. gooseneck mirror.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Detection distance in the unrestricted condition was significantly higher than in all other conditions. The two observation aids conditions had significantly higher detection distances compared to the restricted condition. The magnitude of the improvement in the observation aid conditions was much smaller for the bike approach than for the car approach.

**Acute angle junction, combined results and summary**

The detection distance results for all permutations conducted at the acute angle junction were combined by creating an average of all detection distances within each condition. The combined variables were then subjected to the same analysis as individual permutations.
All comparisons were statistically significant, with the exception of junction camera vs. gooseneck mirror:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

At the acute angle junction, detection distance for the car and the bike was significantly higher in the unrestricted condition than in all other conditions. The observation aids, junction camera and gooseneck mirror, both significantly improved detection distance. However, detection distance in both of these conditions was still significantly lower than in the unrestricted condition. There was no significant difference between the junction camera and gooseneck mirrors.

**All junction permutations combined results**

The results of all junction permutations combined show significant differences between all pairs with the exception of junction camera vs. gooseneck mirror.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)

The pattern of results shows that detection distance was significantly greater in the unrestricted condition than in any other condition. Detection distance in the junction camera and gooseneck mirror conditions was significantly higher than in the restricted condition. This suggests that the devices compensate for restricted movement to a certain extent, but detection distance in the device conditions was still significantly lower than in the unrestricted condition.

**Detection distances and equivalent sight times**

The detection distances achieved in the trial can be converted to sight times for different traffic speeds (see
Table 12) to give an indication of the benefit in terms of decision making.
Table 12 Detection distances for each permutation converted to sight times for different speeds

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean detection distance (m) 2 d.p.</th>
<th>Mean sight time at 30, 40 and 50mph (s) 2 d.p.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unr</td>
<td>R</td>
</tr>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>91.45</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>6.82</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>4.08</td>
</tr>
<tr>
<td>Car, left approach</td>
<td>Mean</td>
<td>90.52</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>6.76</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>5.06</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>4.04</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>90.90</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>6.78</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>4.06</td>
</tr>
<tr>
<td>Bike, left approach</td>
<td>Mean</td>
<td>90.90</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>6.78</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>4.06</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>88.42</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>6.60</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>4.94</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>3.95</td>
</tr>
<tr>
<td>Acute angle junction</td>
<td>Car, right approach</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>12.25</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>9.17</td>
</tr>
<tr>
<td></td>
<td>50mph</td>
<td>7.33</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>163.25</td>
</tr>
<tr>
<td></td>
<td>30mph</td>
<td>12.18</td>
</tr>
<tr>
<td></td>
<td>40mph</td>
<td>9.12</td>
</tr>
</tbody>
</table>
### I.1.2 Detection distance – comparison between artificially restricted and validation participants

Statistical comparisons between the artificially restricted and the validation participants were conducted using the Mann Whitney U test. In the artificially restricted participants’ analysis, the pattern of results for permutations within a junction was found to be similar and the pattern of results for each junction was found to be different. Therefore, only the combined results for each junction separately have been analysed here.

Mean detection distances for the artificially restricted and validation participants at the 90° angle junction are shown in Figure 74.

The graph shows that the patterns of results for the artificially restricted and validation participants are quite different. The impairment of the artificially restricted participants was significantly more severe than that of the validation participants ($Z = -2.124$, $p = 0.036$). There were no significant differences between participant groups within the observation device conditions.
For artificially restricted participants there were no significant differences between the restricted condition and the device conditions. For the validation participants, the detection distance in the gooseneck mirror condition was significantly lower than that in the without devices condition ($\chi^2 = 4.0, p = 0.046$) and in the junction camera condition ($\chi^2 = 4.0, p = 0.046$).

Mean detection distance for artificially restricted and validation participants is shown in Figure 75.

---

19 Note: no data was collected for validation participants in an unrestricted condition so the measure is shown as zero.
Once again, the restriction imposed artificially was found to produce a significantly greater impairment than observed in the validation participants \( (Z = -2.551, p = 0.011) \). The graph also shows that the variability of results in the validation participants without devices condition was much higher than artificially restricted participants in the restricted condition. This indicates that people with restricted neck/trunk movement vary greatly in their ability to turn and look, particularly at an acute angle junction. The coping strategies used to maximise observation ability were also permitted during the trial and would have contributed to the variability of the results. The artificially restricted participants’ restricted condition can be said to represent severely restricted individuals without the benefit of coping strategies. There were no significant differences between participant groups within the observation device conditions.

For artificially restricted participants, both of the observation aids were found to have a significant benefit in terms of detection distance at the acute angle junction. For the validation participants alone there were no significant differences between the without devices condition and the two observation aids condition which suggests that these particular participants did not find them of any significant benefit. The mean detection distances suggest that the devices resulted in reduced detection distance compared to the without devices condition for validation participants.

### I.1.3 Detection distance overall summary

The results of the detection distance task indicate that the junction camera and gooseneck mirror can aid artificially restricted participants in terms of providing additional time to view
vehicles approaching a junction. The benefit of the devices was most evident at the junction with an acute angle to the right. This type of junction was predicted to be most problematic for restricted drivers based on the field of view and user survey results and this was confirmed by the very short detection distance observed in the restricted condition at this junction.

Analysis of the validation participants’ data indicated that the artificial restriction imposed was more limiting than the real restriction experienced by disabled volunteers and that the validation participants were more variable in their abilities. The same significant benefit of the devices at the acute angle junction was not observed in the validation participants. The results of the artificially restricted participants should therefore be interpreted as representative of very severely restricted movement.

Despite this, the junction camera or gooseneck mirror may still provide benefit to less severely restricted people as it may reduce the need for them to make painful turning movements to monitor traffic.

In any case, the benefit provided by the junction camera and gooseneck mirror did not appear to compensate to the level of the unrestricted performance. Additionally, the benefit of both devices was much less evident for detection of a cyclist compared to detection of a car.

In some circumstances, the gooseneck mirror resulted in a minor decrease in detection distance compared to the restricted condition (non-significant). Some participants may have been focussed on the mirror image and not realised that the vehicle had come into view using direct vision. This highlights the need for users to be aware of the capabilities and limitations of any observation device they employ.

For all permutations within the artificially restricted participants there was very little difference in detection distance between the junction camera and the gooseneck mirrors. However, within the validation participants there was a significant difference between the gooseneck mirror and the junction camera at the 90° angle junction.

I.1.4 Subjective ease or difficulty of detection – artificially restricted participants

This section describes the analysis of the subjective ratings of the ease or difficulty of detection for the ten artificially restricted participants for each permutation studied. Unless otherwise stated, all analyses in this section were conducted using a series of Friedman tests to examine the pairs:

1. Unrestricted vs. Restricted
2. Unrestricted vs. Junction camera
3. Unrestricted vs. Gooseneck mirror
4. Restricted vs. Junction camera
5. Restricted vs. Gooseneck mirror
6. Junction camera vs. Gooseneck mirror

Descriptive statistics

Table 13 shows the mean subjective ratings given in response to the question “How easy or difficult was it to detect the on-coming vehicle?” on a ten-point rating scale from 1, “Extremely difficult” to 10, “Extremely easy”. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if participants perceived an improvement (i.e. a more positive rating of ease) compared to the restricted condition and coloured red if ratings in the device condition were worse on average compared to the restricted condition. The measures are coloured blue if the
difference between the restricted condition and the device condition was less than one rating point. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

Table 13 Mean subjective ratings of ease of detection per permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean rating of ease of detection 2 d.p.</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>9.10</td>
<td>1.10</td>
<td>4.60</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
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<td>9.10</td>
<td>0.88</td>
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<td>1.70</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.50</td>
<td>1.27</td>
<td>4.60</td>
<td>1.77</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.60</td>
<td>1.51</td>
<td>5.30</td>
<td>2.41</td>
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<tr>
<td></td>
<td></td>
<td>8.83</td>
<td>0.96</td>
<td>5.05</td>
<td>2.87</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>9.70</td>
<td>0.48</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>9.40</td>
<td>0.70</td>
<td>2.50</td>
<td>2.17</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.55</td>
<td>0.55</td>
<td>2.30</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>9.15</td>
<td>0.77</td>
<td>4.20</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

Across both junctions and all permutations, the ratings of ease of detection in the unrestricted condition were highly positive.

For the majority of the 90° angle junction permutations ratings of ease of detection (with the exception of the car approach from the right) were only slightly higher in the device
conditions than in the restricted condition. At the 90° angle junction, ratings in the restricted, junction camera and gooseneck mirror condition tended to be around the mid-point of the scale which suggests that the artificially restricted participants found it neither particularly easy nor particularly difficult to detect the on-coming vehicles.

At the acute angle junction ratings of ease of detection were very low in the restricted condition, suggesting that participants found it very difficult to detect the on-coming vehicles when artificially restricted. Ratings in the device conditions were moderately positive compared to the restricted condition which indicates that participants found it reasonably easy to detect the on-coming vehicles using the observation aids at the acute angle junction.

The following sections describe the statistical testing that has been conducted on these results.

**90° angle junction, car approach from the right**
Ease of detection was rated significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 7.0, p = 0.008$)

The difference in mean ratings between the device conditions and the restricted condition neared significance:
- Restricted vs. Junction camera ($\chi^2 = 3.6, p = 0.058$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 3.571, p = 0.059$)

On average, ratings of the ease of detection in junction camera and gooseneck mirror conditions were higher than in the restricted condition. There was no significant difference in ratings between the junction camera and gooseneck mirror conditions.

**90° angle junction, car approach from the left**
Ease of detection was rated significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 8.0, p = 0.005$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)

There were no other significant differences between conditions. This suggests that for car approaches from the left at the 90° junction, artificially restricted participants found detection no easier in the observation aid conditions than in the restricted condition.

**90° angle junction, bike approach from the right**
Ease of detection was rated significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 9.0, p = 0.003$)
Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
Unrestricted vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

The difference in ratings between the restricted and gooseneck mirror conditions approached significance:
- Restricted vs. Gooseneck mirror ($\chi^2 = 3.571, p = 0.059$)

The ratings for ease of detection given in the gooseneck mirror condition were slightly higher than those given in the restricted condition. There were no other significant differences between conditions.

**90° angle junction, bike approach from the left**
Ease of detection was rated significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 8.0, p = 0.005$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)

Ease of detection was rated significantly lower in the gooseneck mirror condition than in the restricted condition:
- Restricted vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

There were no other significant differences between conditions.

**90° angle junction, combined results and summary**
An aggregated measure of subjective ease of detection was created by calculating an average rating across all permutations for each participant.

Ratings of ease of detection were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.02$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Mean ratings in the gooseneck mirror condition for 90° angle junction permutations combined were significantly higher than in the restricted condition:
- Restricted vs. Gooseneck mirror ($\chi^2 = 5.444, p = 0.02$)

However, this difference was less than one rating point in magnitude.

There were no other significant differences between conditions for the mean rating of ease of detection across all conditions.

For most permutations at the 90° angle junction, with the exception of the car approach from the right, the increase in ratings of ease of detection in the device conditions compared to the
restricted condition was marginal. Ratings of ease of detection in the unrestricted condition far exceeded those in all other conditions.

**Acute angle junction, car approach from the right**

There were significant differences in subjective ratings of ease of detection between all pairs, with the exception of junction camera vs. gooseneck mirror:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Ratings were significantly higher than in the unrestricted condition than in any other condition. Ratings in the junction camera and gooseneck mirror conditions were significantly higher than in the restricted condition.

**Acute angle junction, bike approach from the right**

As for car approaches, there were significant differences in subjective ratings of ease of detection between all pairs with the exception of junction camera vs. gooseneck mirror.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)

The pattern of results was the same as that for the car approach; ratings were significantly higher in the unrestricted condition compared to all other conditions. Ratings in junction camera and gooseneck mirror conditions were significantly higher than in the restricted condition.

**Acute angle junction, combined results and summary**

The ratings for the car and bike approaches to the acute angle junction were combined by creating an average for each participant in each condition. Pairs of average ratings were then compared as in previous analyses.

There were significant differences in subjective ratings of ease of detection between all pairs with the exception of junction camera vs. gooseneck mirror.

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
• Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Ratings were significantly higher in the unrestricted condition compared to all other conditions. Ratings in the junction camera and gooseneck mirror conditions were significantly higher than in the restricted condition. However, the ratings did not reach the level of the unrestricted condition. This suggests that the artificially restricted participants did not find it as easy to detect the on-coming vehicles using the observation aids than it was using direct vision in the unrestricted condition.

All results combined

When the results for both junctions and all permutations were combined and analysed, subjective ratings of ease of detection were significantly higher in the unrestricted condition compared to all other conditions:
• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
• Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Ratings in the gooseneck mirror condition were significantly higher than in the restricted condition:
• Restricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = .011$)

The difference in ratings in the restricted condition and the junction camera condition approached significance:
• Restricted vs. Junction camera ($\chi^2 = 3.6, p = 0.058$)

There was no significant difference between the junction camera and gooseneck mirror condition.

I.1.5 Subjective ease or difficulty of detection – validation participants

For the artificially restricted participants, the only significant difference between the restricted and device conditions was that the gooseneck mirror was rated significantly higher than the restricted condition for ease of detection. For the validation participants, the opposite was true and the gooseneck mirror was rated significantly lower than the without devices condition for ease of detection ($\chi^2 = 4.0, p = 0.046$). There was also a significant difference between the junction camera and gooseneck mirror conditions; the junction camera was rated more highly than the gooseneck mirror ($\chi^2 = 4.0, p = 0.046$).

For both sets of participants the pattern of ratings given was broadly consistent with the detection distances achieved in each condition at the 90° angle junction.

Ratings of ease of detection appear to be higher in the validation participants “without devices” condition compared to the artificially restricted participants restricted condition but this difference did not reach significance ($Z = -1.707, p = 0.089$). Validation participants also gave significantly higher ratings of ease of detection for the junction camera than the artificially restricted participants gave ($Z = -2.847, p = 0.003$).
For the artificially restricted participants, the only significant difference between the restricted and device conditions was that the gooseneck mirror was rated significantly higher than the restricted condition for ease of detection. For the validation participants, the opposite was true and the gooseneck mirror was rated significantly lower than the without devices condition for ease of detection ($\chi^2 = 4.0, p = 0.046$). There was also a significant difference between the junction camera and gooseneck mirror conditions; the junction camera was rated more highly than the gooseneck mirror ($\chi^2 = 4.0, p = 0.046$).

For both sets of participants the pattern of ratings given was broadly consistent with the detection distances achieved in each condition at the 90° angle junction.

Validation participants’ ratings of ease of detection in the without devices (restricted) condition was significantly higher than the artificially restricted participants’ ratings ($Z = -2.229, p = 0.026$). This again reinforces the conclusion that the artificially restricted participants’ restricted condition should be seen as representative of very severe restricted movement in the real world.

Ratings of ease of detection using the gooseneck mirror were lower in the validation group compared to the artificially restricted group and this difference approached significance ($Z = -1.810, p = 0.076$).

Within the artificially restricted group, ease of detection was rated significantly more highly in both of the observation aid conditions compared to the restricted condition. Within the validation participant group there was no significant difference between the without devices condition and either of the observation aid conditions.

**Subjective ease or difficulty of detection overall summary**

For the artificially restricted group, at both junctions and across all permutations, ratings of ease of detection were highly positive in the unrestricted condition and significantly higher than all other conditions.

At the 90° angle junction, ratings on the restricted condition tended to be around the mid point of the scale, indicating that although the artificially restricted participants found it more difficult to detect the on-coming vehicles than in the unrestricted condition they did not find it particularly difficult overall. At the same junction, validation participants in the without devices condition gave significantly more positive ratings than the artificially restricted participants. This suggests that many people with restricted movement would not find this type of junction problematic.

For the artificially restricted participants, the observation aids provided only slightly easier detection than the restricted condition and this increase was not significant for most permutations. The exception to this was the car approach from the right at the 90° angle junction, where participants found the observation aids more beneficial. Validation participants rated the junction camera slightly more highly than the without devices condition (non-significant) but the gooseneck mirror was rated significantly lower (i.e. more difficult to
detect the on-coming vehicle) than the without devices condition. This is likely because they did not find the task difficult even without any aids.

At the acute angle junction, ratings given in the restricted condition were very low. This indicates that participants found it very difficult to detect the on-coming car and cyclist under these circumstances. At this junction validation participants gave lower rating than they did for the 90° angle junction but ratings were still slightly above the mid point of the scale.

Ratings for the observations aids were significantly higher than the restricted condition, which shows that participants found the aids more beneficial at the more difficult junction. This pattern was not replicated in the validation participants.

The pattern of ratings of ease of detection was consistent with the mean detection distances achieved under the various conditions for both groups of participants.

1.1.6 Clarity of view – artificially restricted participants

Descriptive statistics
Table 14 shows the mean subjective ratings given in response to the question “How clearly could you see and recognise the on-coming vehicle?” on a ten-point rating scale from 1, “Extremely ambiguously” to 10, “Extremely clearly”. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if participants perceived an improvement (i.e. a more positive rating of clarity) compared to the restricted condition and coloured red if ratings in the device condition were worse on average compared to the restricted condition. The measures are coloured blue if the difference between the restricted condition and the device condition was less than one rating point. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.
Table 14 Mean subjective rating of clarity of view per permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean subjective rating of clarity (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>8.40</td>
<td>4.70</td>
<td>5.50</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.17</td>
<td>2.50</td>
<td>2.37</td>
<td>2.78</td>
</tr>
<tr>
<td>Car, left approach</td>
<td>Mean</td>
<td>7.80</td>
<td>5.20</td>
<td>5.40</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.75</td>
<td>3.08</td>
<td>2.63</td>
<td>2.97</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>6.80</td>
<td>3.80</td>
<td>3.70</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.30</td>
<td>2.94</td>
<td>1.49</td>
<td>2.83</td>
</tr>
<tr>
<td>Bike, left approach</td>
<td>Mean</td>
<td>7.40</td>
<td>4.80</td>
<td>4.20</td>
<td>4.40</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>3.03</td>
<td>3.33</td>
<td>3.01</td>
<td>3.44</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>7.70</td>
<td>4.73</td>
<td>5.00</td>
<td>4.90</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.32</td>
<td>2.73</td>
<td>2.04</td>
<td>2.72</td>
</tr>
<tr>
<td>Acute angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>9.70</td>
<td>3.80</td>
<td>4.30</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.48</td>
<td>3.08</td>
<td>2.63</td>
<td>2.20</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>8.10</td>
<td>3.50</td>
<td>3.60</td>
<td>3.30</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.66</td>
<td>3.06</td>
<td>1.96</td>
<td>1.64</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>8.90</td>
<td>3.65</td>
<td>3.95</td>
<td>4.05</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.94</td>
<td>2.98</td>
<td>2.14</td>
<td>1.48</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>8.10</td>
<td>4.37</td>
<td>4.65</td>
<td>4.62</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.10</td>
<td>2.66</td>
<td>1.89</td>
<td>1.57</td>
</tr>
</tbody>
</table>

Ratings of clarity of view in the unrestricted condition were moderately to highly positive. Ratings for the 90° angle junction were lower on average than those for the acute angle junction and this is likely due to fences and foliage at the 90° angle junction which partially masked the approaching vehicles.

Ratings in the restricted condition tended to be slightly below the mid point of the scale on average. Although the approaching vehicles were viewed directly, the clarity of the view may have been rated low because the artificially participants had to rely on peripheral vision to
achieve the earliest detection. The observation devices received very similar ratings for clarity to the restricted condition.

The following sections describe the statistical testing that has been conducted on these results.

90° angle junction, car approach from the right
Participant ratings of the clarity of the view at the 90° angle junction for the car approach from the right were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 8.0$, $p = 0.005$)
- Unrestricted vs. Junction camera ($\chi^2 = 8.0$, $p = 0.005$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 4.5$, $p = 0.034$)

There were no other significant differences between conditions.

90° angle junction, car approach from the left
Participant ratings of the clarity of the view at the 90° angle junction for the car approach from the left were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 8.0$, $p = 0.005$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4$, $p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 4.5$, $p = 0.034$)

There were no other significant differences between conditions.

90° angle junction, bike approach from the right
Participant ratings of the clarity of the view at the 90° angle junction for the car approach from the left were significantly higher in the unrestricted condition than in the restricted and junction camera conditions:

- Unrestricted vs. Restricted ($\chi^2 = 7.0$, $p = 0.008$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4$, $p = 0.011$)

The difference between the unrestricted and gooseneck mirror conditions approached significance:

- Unrestricted vs. Gooseneck mirror ($\chi^2 = 3.571$, $p = 0.059$)

There were no other significant differences between conditions.
90° angle junction, bike approach from the left
Participant ratings of the clarity of the view at the 90° angle junction for the car approach from the left were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 5.444, p = 0.02$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 5.444, p = 0.02$)

There were no other significant differences between conditions.

90° angle junction, combined results and summary
The results for all the permutations conducted at the 90° angle junction were combined by calculating an average across all permutations for each condition. This combined measure was then subjected to the same analysis as individual permutations.

Mean participant ratings of the clarity of the view at the 90° angle junction were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)

There were no other significant differences between conditions. This pattern was true of all permutations at the 90° angle junction.

Acute angle junction, car approach from the right
Participant ratings of the clarity of the view at the acute angle junction for the car approach from the right were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significant differences between conditions.

Acute angle junction, bike approach from the left
Participant ratings of the clarity of the view at the acute angle junction for the car approach from the left were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
There were no other significant differences between conditions.

**Acute angle junction, combined results and summary**

Participant ratings of clarity for the two permutations conducted at the acute angle junction were averaged to create a combined measure of subjective clarity for each condition.

The overall rating of clarity at the acute angle junction was significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There were no other significantly different conditions.

This pattern was observed in both individual permutations at this junction.

**All results combined**

All participant ratings of clarity for all permutation studies were averaged to create an overall measure. This was then analysed according to the same method as the single permutation analyses.

Again, ratings in the unrestricted condition were significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

The difference between the restricted condition and the gooseneck mirror condition approached significance:

- Restricted vs. Gooseneck mirror ($\chi^2 = 3.6, p = 0.058$)

There was no significant difference between the restricted and the junction camera conditions or between the gooseneck mirror and junction camera conditions.

**I.1.7 Comparison between artificially restricted and validation participants**

The pattern of results for the validation participants at the 90° angle junction differed from that of the artificially restricted participants. The statistical comparison shows that the validation participants rated clarity of the view significantly higher in the without devices condition than artificially restricted participants in the restricted condition ($Z = -2.607, p = 0.039$). This may be because the restriction on the artificially restricted participants was more severe so they used peripheral vision more than the validation participants who tended to turn their head at this junction. The clarity of view provided by the junction camera was also rated
more highly by the validation participants than by the artificially restricted participants \( (Z = -2.417, p = 0.014) \)

Within the validation participants there was a significant difference between the without devices and gooseneck mirror condition. No such significant difference was observed within the artificially restricted participants. This result is consistent with the validation participant results for both detection distance and ease of detection which suggest that they found the junction camera more beneficial than the gooseneck mirrors at this junction.

At the acute angle junction, the patterns of results for the artificially restricted and the validation participants were not significantly different. As at the 90° angle junction, the validation participants rated clarity significantly more highly than the artificially restricted participants in the without devices/restricted condition \( (Z = -2.229, p = 0.26) \). However, within the validation participants group there were no significant differences between the without devices condition and the device conditions and this was also the case within the artificially restricted participants group.

Subjective clarity of view overall summary
The artificially restricted participants rated clarity of view highly in the unrestricted condition and ratings in this condition were significantly higher than in all other conditions. Despite the fact that the unrestricted condition afforded free and direct view of the on-coming vehicles the highest possible rating was not given. This is likely due to the obstruction of view produced by fencing and foliage, particularly at the 90° angle junction.

Ratings for clarity given in the restricted condition tended to be just below the mid point of the scale. This suggests that artificially restricted participants found the view in this condition neither particularly clear nor particularly ambiguous. In the restricted condition, the participants were relying on their peripheral vision to achieve the earliest possible detection of the vehicle and this is the most probable explanation for the low ratings given even though the stimuli were viewed directly. In contrast, the validation participants rated the clarity of view reasonably highly in the without devices condition and this may be because they were generally able to turn to look at the on-coming vehicle to some extent.

Artificially restricted participants’ ratings of clarity given in the two observation aids conditions were very similar to those given in the restricted condition and there were no significant differences. Clarity of view in the device conditions would have been limited by the quality of the screen/mirrors. The mean ratings for these conditions suggested that participants found the views neither particularly clear nor particularly unclear. There were no differences in ratings between the junction camera and the gooseneck mirror. The pattern of validation participant ratings was generally similar except for at the 90° angle junction where they rated the clarity of view provided by the gooseneck mirror condition lower than that provided by the junction camera.

I.1.8 Confidence – artificially restricted participants

Descriptive statistics
Table 15 shows the mean subjective ratings given in response to the question “How confident or unconfident would you feel pulling out at this junction using this observation method?” on a ten-point rating scale from 1, “Extremely unsure” to 10, “Extremely confident”. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if participants perceived an improvement (i.e. a more
positive rating of confidence) compared to the restricted condition and coloured red if ratings in the device condition were worse on average compared to the restricted condition. The measures are coloured blue if the difference between the restricted condition and the device condition was less than one rating point. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

Mean ratings of confidence were high in the unrestricted condition. The acute angle junction received higher ratings of confidence on average than the 90° angle junction despite the difficulty posed by the sharp angle. The detection distance results indicate that unrestricted participants could see further at this junction and the view was unobscured by fencing and vegetation and the higher confidence ratings correspond to this.
### Table 15 Mean rating of confidence per permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean subjective rating of confidence (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>9.20</td>
<td>3.80</td>
<td>5.40</td>
<td>4.40</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.92</td>
<td>3.011</td>
<td>2.27</td>
<td>2.17</td>
</tr>
<tr>
<td>Car, left approach</td>
<td>Mean</td>
<td>8.50</td>
<td>5.40</td>
<td>3.90</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.42</td>
<td>3.20</td>
<td>2.32</td>
<td>2.28</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>7.90</td>
<td>3.90</td>
<td>3.90</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.97</td>
<td>3.14</td>
<td>1.52</td>
<td>2.94</td>
</tr>
<tr>
<td>Bike, left approach</td>
<td>Mean</td>
<td>7.80</td>
<td>5.00</td>
<td>4.30</td>
<td>4.70</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.78</td>
<td>3.27</td>
<td>2.71</td>
<td>3.50</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>8.53</td>
<td>4.12</td>
<td>5.03</td>
<td>4.00</td>
</tr>
<tr>
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<td>S.D.</td>
<td>1.65</td>
<td>3.02</td>
<td>1.39</td>
<td>2.30</td>
</tr>
<tr>
<td>Acute angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car, right approach</td>
<td>Mean</td>
<td>10.0</td>
<td>1.40</td>
<td>5.50</td>
<td>4.70</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.00</td>
<td>0.84</td>
<td>2.37</td>
<td>2.98</td>
</tr>
<tr>
<td>Bike, right approach</td>
<td>Mean</td>
<td>9.90</td>
<td>1.40</td>
<td>5.10</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.32</td>
<td>0.84</td>
<td>1.85</td>
<td>1.94</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
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<td>1.40</td>
<td>5.30</td>
<td>4.35</td>
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<td>S.D.</td>
<td>0.16</td>
<td>0.84</td>
<td>1.81</td>
<td>1.90</td>
</tr>
<tr>
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<td>3.22</td>
<td>5.12</td>
<td>4.12</td>
</tr>
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<td>1.11</td>
<td>2.17</td>
<td>0.79</td>
<td>1.87</td>
</tr>
</tbody>
</table>

Ratings of confidence at the 90° angle junction were slightly below the mid point of the scale for all permutations. This suggests that at this junction participants felt that would be slightly unsure if pulling out at this junction while restricted. In contrast, the ratings given during the restricted condition at the acute angle junction were very low, which suggests that participants would have felt extremely unsure pulling out under these circumstances.

At the 90° angle junction confidence ratings given in the observation device conditions tended to be only slightly higher than those given in the restricted condition. At the acute angle
junction the junction camera and gooseneck mirror produced more positive ratings than the restricted condition. The junction camera tended to be associated with slightly higher ratings of confidence than that gooseneck mirror. However, the ratings for both devices still tended to be around the mid point of the scale which suggests that participants felt neither particularly unsure nor particularly confident. The device ratings were still much lower than those given in the unrestricted condition.

The following sections describe the statistical testing that has been conducted on these results.

**90° angle junction, car approach from the right**
Ratings of confidence were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

The difference in confidence ratings between the restricted condition and the gooseneck mirror condition approached significance:
- Restricted vs. Gooseneck mirror ($\chi^2 = 3.571, p = 0.059$)

There were no other significant differences between conditions.

**90° angle junction, car approach from the left**
Ratings of confidence were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There was also a significant difference between the junction camera and gooseneck mirror condition:
- Junction camera vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

Ratings of confidence were significantly higher in the junction camera condition than in the gooseneck mirror condition. There were no significant differences between the restricted and junction camera conditions or the restricted and gooseneck mirror conditions.

**90° angle junction, bike approach from the right**
Ratings of confidence were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)

There were no other significant differences between conditions.
90° angle junction, bike approach from the left
Ratings of confidence were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 9.0$, $p = 0.003$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0$, $p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 8.0$, $p = 0.005$)
There were no other significant differences between conditions.

90° angle junction, combined results and summary
Ratings of confidence were significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.0$, $p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4$, $p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0$, $p = 0.002$)
There were no other significant differences between conditions.

This pattern of results was true for all permutations at the 90° angle junction. The observation aids did not increase participant ratings of confidence significantly compared to the restricted condition.

Acute angle junction, car approach from the right
There were significant differences between all comparison pairs with the exception of junction camera vs. gooseneck mirror:
- Unrestricted vs. Restricted ($\chi^2 = 10.0$, $p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0$, $p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0$, $p = 0.003$)
- Restricted vs. Junction camera ($\chi^2 = 9.0$, $p = 0.003$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 9.0$, $p = 0.003$)
The junction camera and gooseneck mirror conditions produced significantly higher ratings than the restricted condition. However, ratings in the unrestricted condition were still significantly higher than those in both of the device conditions.

Acute angle junction, bike approach from the right
There were significant differences between all comparison pairs with the exception of junction camera vs. gooseneck mirror:
- Unrestricted vs. Restricted ($\chi^2 = 10.0$, $p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0$, $p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0$, $p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0$, $p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 9.0$, $p = 0.003$)
The junction camera and gooseneck mirror conditions produced significantly higher ratings than the restricted condition. However, ratings in the unrestricted condition were still significantly higher than those in both of the device conditions.

**Acute angle junction, combined results and summary**

There were significant differences between all comparison pairs with the exception of junction camera vs. gooseneck mirror:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

The junction camera and gooseneck mirror conditions produced significantly improved confidence ratings compared to the restricted condition. However, ratings in the unrestricted condition were still significantly higher than those in both of the device conditions. This pattern of results was true for both permutations of the test at the acute angle junction.

**All results combined**

When the ratings of confidence from all permutations were combined, the mean rating was significantly higher in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Ratings of confidence in the gooseneck mirror condition were significantly higher than those in the restricted condition:

- Restricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)

**I.1.9 Comparison between artificially restricted and validation participants**

The mean confidence ratings give at the 90° angle junction for artificially restricted and validation participants. Validation participant ratings were significantly higher than the artificially restricted participants for the restricted/without devices and junction camera conditions. The validation participants may be expected to be confident in the without devices condition as this is their usual observation method when driving in the real world.

For both the validation and the artificially restricted participants there were no significant differences between the restricted/without devices condition and either of the observation aids conditions. Although for the validation participants the difference between the without devices and the gooseneck mirror condition approached significance ($\chi^2 = 3.0, p = 0.083$)

At the acute angle junction there was a difference in the pattern of confidence ratings between the artificially restricted and the validation participants. Artificially restricted participants
rated their confidence significantly higher in both of the device conditions compared to the restricted condition. For validation participants there were no significant differences between the without devices condition and the two observation aid conditions. Validation participants had higher confidence than artificially restricted participants at this junction (Z = -2.311, p = 0.021).

In comparison to the 90° angle junction the validation participants gave lower ratings of confidence at the acute angle junction and this validates the assumption that acute angle junctions pose more difficulty for people with restricted neck and trunk movement, even though they may be able to achieve reasonable detection distances.

**Participant confidence overall summary**
Participant confidence ratings were generally in line with the pattern of detection distances observed.

In all permutations, the artificially restricted participants’ confidence rating for the unrestricted condition far exceeded the ratings given in all other conditions.

The confidence ratings given by validation participants in the without devices condition exceeded those given by the artificially restricted participants in the restricted condition. The validation participants normally drive without devices and are therefore reasonably confident in this situation even though they have restricted movement to various degrees.

For both groups, ratings of confidence given at the 90° angle junction in the device conditions were similar to those given in the restricted/without devices condition. This is in line with the junction detection results that showed no significant improvements in the device conditions compared to the restricted condition. For validation participants the difference between the gooseneck mirror condition and the without devices condition approached significance and this is consistent with the finding that at this junction, detection distance was shorter in the gooseneck mirror condition than in the without devices condition.

At the acute angle junction, ratings of confidence in the restricted condition were very low due to the difficulty of the junction and the extreme limitation on viewing distance imposed by the artificial restriction. Validation participant ratings were also lower at this junction than at the 90° angle junction but they were still higher than those of the artificially restricted participants. Artificially restricted participant ratings of confidence in the device conditions were significantly higher than those given in the restricted condition. This reflects the improved detection distances in these conditions at the acute angle junction. The same was not true of the validation participants. They had not experienced that same benefit of the aids in terms of improved detection distances and correspondingly there were no significant changes in their ratings of confidence.

As with the other measures captured during this study, there were no prominent differences between the junction camera and the gooseneck mirror conditions.
1.2 Junction usability

The junction usability task collected four different numerical measures:

1. **Time** – The time taken to drive up to the junction from the starting point, check it was clear, make the turn and pull up at the end point.

2. **Ease of checking** – a subjective rating made by the participant on a 10-point scale in response to the question: “*How easy or difficult was it to ensure that it was clear?*”

3. **Confidence** - a subjective rating made by the participant on a 10-point scale in response to the question: “*How confident or unconfident did you feel using this observation method?*”

4. **Quality of view** - a subjective rating made by the participant on a 10-point scale in response to the question: “*How good or bad was the view given by this observation method?*”

Subjective comments and observations of user behaviour and usability issues were also recorded.

Analysis of each measure is presented in the following sections for both the artificially restricted participants and the validation participants.

### 1.2.1 Time taken

#### 1.2.1.1 Artificially restricted participants

**Descriptive statistics**

Table 16 shows the mean and standard deviation of the time taken to make turns under the various observation conditions. Means were calculated across all artificially restricted participants and for each permutation of the junction usability test. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if there was an improvement (i.e. a faster turn time) compared to the restricted condition and coloured red if there was a reduction in the time (i.e. if performance was worse/task more difficult) compared to the restricted condition. The measures are coloured blue if the difference between the restricted condition and the device condition was less than one second. Figures shown in brackets below the means indicated the magnitude and direction of the difference between the device conditions and the restricted condition.
Table 16 Mean time taken to make turn, artificially restricted participants

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean time (s) 2 d.p.</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>18.55</td>
<td>24.60</td>
<td>25.98</td>
<td>27.22</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.16</td>
<td>8.46</td>
<td>3.96</td>
<td>4.27</td>
</tr>
<tr>
<td>Left turn</td>
<td>Mean</td>
<td>18.68</td>
<td>29.76</td>
<td>30.62</td>
<td>26.02</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.54</td>
<td>11.17</td>
<td>12.37</td>
<td>4.40</td>
</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>18.62</td>
<td>27.18</td>
<td>28.30</td>
<td>26.62</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.28</td>
<td>9.65</td>
<td>5.93</td>
<td>3.53</td>
</tr>
<tr>
<td>Acute angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>19.59</td>
<td>25.86</td>
<td>36.83</td>
<td>31.25</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
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<td>10.73</td>
<td>9.35</td>
<td>14.45</td>
</tr>
<tr>
<td>Left turn</td>
<td>Mean</td>
<td>19.07</td>
<td>26.59</td>
<td>35.52</td>
<td>28.94</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>3.43</td>
<td>6.56</td>
<td>21.18</td>
<td>9.47</td>
</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>19.33</td>
<td>26.22</td>
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<td>30.10</td>
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<tr>
<td></td>
<td>S.D.</td>
<td>3.32</td>
<td>7.34</td>
<td>14.13</td>
<td>11.53</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>19.07</td>
<td>26.70</td>
<td>32.24</td>
<td>28.36</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.79</td>
<td>7.98</td>
<td>9.07</td>
<td>8.87</td>
</tr>
</tbody>
</table>

The descriptive statistics show that participants made the turn most quickly in the unrestricted condition on all occasions. The average time taken to make the turns was generally higher in the junction camera and gooseneck mirror conditions compared to the restricted condition.

90° angle junction right turn

When turning right at the 90° angle junction participants were significantly slower in the junction camera and gooseneck mirror mirror conditions compared to the unrestricted condition:

- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Participants were also slower in the restricted condition compared to the unrestricted condition and this difference approached significance:

- Unrestricted vs. Restricted ($\chi^2 = 3.6, p = 0.058$)

The turns were also significantly slower in gooseneck mirror condition compared to the restricted condition without any devices:

- Restricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)
There were no other significant differences.

**90° angle junction left turn**
When turning left at the 90° angle junction participants were significantly faster in the unrestricted condition compared to all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)

The observation aids conditions were neither significantly faster nor significantly slower than the restricted condition and there was no significant difference between them.

**Acute angle junction right turn**
The time taken in the unrestricted condition was significantly less than in the junction camera and gooseneck mirror conditions:

- Unrestricted vs. Junction camera ($\chi^2 = 10.0 = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 6.4 = 0.011$)

The time in the unrestricted condition was also less than in the restricted condition but this difference did not achieve significance:

- Unrestricted vs. Restricted ($\chi^2 = 3.6 = 0.058$)

The two observation aid conditions were both associated with longer manoeuvre times than the restricted condition. The difference between the gooseneck mirror and restricted conditions was significant but the difference between with junction camera and the restricted condition did not achieve significance.

- Restricted vs. Junction camera ($\chi^2 = 3.6, p = 0.058$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

**Acute angle junction left turn**
The time taken in the unrestricted condition was significantly less than in all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 5.444 = 0.02$)
- Unrestricted vs. Junction camera ($\chi^2 = 10.0 = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0 = 0.002$)

There were no other significant differences between conditions.

**Artificially restricted participants, time taken summary**
Participants tended to make the turn faster in the unrestricted condition compared to all other conditions. This is as would be expected given that this was the most familiar observation method for the artificially restricted participants.

For the majority of permutations, the mean time taken was higher in the device conditions than in the restricted condition. These differences were statistically significant for some analyses. The increase in time was most evident for right turns where drivers are required to look both ways. This increase in time when using the observation aids could be due to the unfamiliarity of the devices and initial usability issues.
There were no significant differences between the time taken using the junction camera and gooseneck mirror, although the means for the acute angle junction show that the time taken in the junction camera condition was longer on average than the time taken in the gooseneck mirror condition.

### 1.2.1.2 Validation participants

The validation participants’ times in the without devices condition tended to be faster than the artificially restricted participants’ times in the restricted condition on average. However, these differences were not significant and there were no significant differences between the groups within either of the device conditions.

This indicates that the two groups were broadly comparable in terms of the time taken to make a turn at the t-junction and that the restricted condition was a valid approximation of people with restricted movement for this measure (time taken to complete a turn). The patterns of results at each junction were also broadly similar except for a few results which achieved significance on one group but not the other. These instances are detailed in the following sections.

### 90° angle junction right turn

Validation participants were significantly slower to make the turn in the junction camera and gooseneck mirror condition than in the without devices condition:

- Without devices vs. Junction camera ($\chi^2 = 4.0, p = 0.046$)
- Without devices vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

Artificially restricted participants also showed this pattern of results but only the difference between the restricted and the gooseneck mirror conditions reached significance.

### 90° angle junction left turn

Validation participants made the turn significantly slower in the junction camera condition compared to the without devices condition ($\chi^2 = 4.0, p = 0.046$). There was no such significant difference within the artificially restricted participant group and the direction of the difference between the mean times in these two conditions was opposite.

### Acute angle junction right turn

In the artificially restricted group, the turn took longer when using the junction camera or the gooseneck mirror compared to the restricted condition. This pattern was also apparent in the validation participants group. The difference between the junction camera and gooseneck mirror condition was significant ($\chi^2 = 4.0, p = 0.046$). Time taken was also higher in the gooseneck mirror condition compared to the without devices condition but this effect did not reach significance.
There were no significant differences between conditions in the validation participant group. This result is entirely consistent with the pattern of results observed in the artificially restricted participant group.

I.2.1.3 Time taken overall summary

Artificially restricted participants took longer to make the turns in the restricted condition compared to the unrestricted condition. This would be expected as the unrestricted condition was the easiest and most familiar to them.

The devices did not seem to produce any benefit in terms of making the process of checking for traffic any faster. The devices were actually associated with significantly slower times for most of the turns in both the validation and artificially restricted participant groups. The increase in time was particularly evident for right turns and this suggests that switching between views could be an issue that may have slowed participants down.

The time taken is not necessarily a valid measure of usability in this context as participants were unfamiliar with the technology which would have affected the time taken.
I.2.2 Ease of checking

I.2.2.1 Artificially restricted participants

Descriptive statistics
Table 17 shows the mean subjective ratings given in response to the question “How easy of difficult was it to ensure that it was clear?” on a ten-point rating scale from 1, “Extremely difficult” to 10, “Extremely easy”. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if participants perceived an improvement (i.e. a more positive rating of ease) compared to the restricted condition and coloured red if ratings in the device condition were worse on average compared to the restricted condition. Figures shown in brackets below the means indicated the magnitude and direction of the difference between the device conditions and the restricted condition.

The means shows that participants found it very easy to check that it was clear during the unrestricted condition. Ratings in the restricted condition were very low on average. This suggests that participants found it very difficult to ensure that it was clear when artificially restricted at both junctions. Both observation aids produced higher ratings than the restricted condition for all permutations of the test. Ratings for the gooseneck mirror were just below the mid point of the scale on average; participants found it neither particularly difficult nor particularly easy to check it was clear using the gooseneck mirrors. Ratings for the junction camera tended to be higher than those given for the gooseneck mirror and were on the positive side of the scale for all permutations.

These observations were examined using statistical tests and the results of these analyses are detailed in the following sections.
<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean rating of ease of checking (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90° angle junction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>9.60</td>
<td>2.50</td>
<td>6.30</td>
<td>4.60</td>
</tr>
<tr>
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<td>(±3.8)</td>
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<td></td>
<td>(+2.1)</td>
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</tr>
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<tr>
<td>Left turn</td>
<td>Mean</td>
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<td>2.90</td>
<td>6.90</td>
<td>5.90</td>
</tr>
<tr>
<td></td>
<td>(±4.0)</td>
<td></td>
<td></td>
<td>(+3.0)</td>
<td></td>
</tr>
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<td>S.D.</td>
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<td>2.18</td>
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</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>9.60</td>
<td>2.70</td>
<td>6.60</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>(±3.9)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>9.50</td>
<td>1.80</td>
<td>5.80</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>(±4.0)</td>
<td></td>
<td></td>
<td>(+3.2)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>0.71</td>
<td>1.93</td>
<td>2.57</td>
<td>3.09</td>
<td></td>
</tr>
<tr>
<td>Left turn</td>
<td>Mean</td>
<td>9.50</td>
<td>1.90</td>
<td>7.00</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>(±5.1)</td>
<td></td>
<td></td>
<td>(+1.9)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>1.08</td>
<td>2.51</td>
<td>1.16</td>
<td>2.46</td>
<td></td>
</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>9.50</td>
<td>1.85</td>
<td>6.40</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>(±4.6)</td>
<td></td>
<td></td>
<td>(+2.4)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>0.85</td>
<td>1.56</td>
<td>1.39</td>
<td>2.34</td>
<td></td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>9.55</td>
<td>2.28</td>
<td>6.50</td>
<td>4.75</td>
</tr>
<tr>
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<td></td>
<td>(+2.47)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>0.51</td>
<td>1.47</td>
<td>0.91</td>
<td>1.96</td>
<td></td>
</tr>
</tbody>
</table>

There were significant differences between all conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 5.444, p = 0.02$)
- Junction camera vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

Ease of checking the junction was clearly rated higher in the unrestricted condition compared to all other conditions. The junction camera and gooseneck mirror conditions were both considered to be significantly easier than the restricted condition, although they were still considered significantly more difficult than the unrestricted condition. The junction camera was rated to be significantly easier to use for checking the junction was clear than the gooseneck mirror.
90° angle junction left turn

The pattern of results for the left turn at the 90° angle junction was the same as that for the right turn:

• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
• Unrestricted vs. Junction camera ($\chi^2 = 9.0, p = 0.003$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)
• Restricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 7.0, p = 0.008$)
• Junction camera vs. Gooseneck mirror ($\chi^2 = 5.0, p = 0.025$)

Acute angle junction right turn

At the acute angle junction, all analysis pairs were significantly different with the exception of junction camera vs. gooseneck mirror:

• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
• Unrestricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)
• Restricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

The pattern of results was the same as that for the 90° angle junction but the difference between the junction camera and gooseneck mirror conditions did not reach significance ($\chi^2 = 2.788, p = 0.096$)

Acute angle junction left turn

All pairs of ratings given for the acute angle junction left turn were significantly different:

• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)
• Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 1.0, p = 0.002$)
• Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)
• Junction camera vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

The pattern of results was the same as that for the 90° angle junction.

Artificially restricted participants, ease of checking summary

For both junctions and directions the unrestricted condition was rated as easiest to check that it was clear. The differences between the unrestricted condition and the other conditions were significant in all cases.

Both observation aids were judged to make it easier to check the junction was clear than the restricted condition. However, the ratings given in these conditions were still significantly lower than the unrestricted condition. This indicates that the artificially restricted volunteers did not judge them to be as easy as driving with no restriction.
Participants found the junction camera easier to use for checking the junction was clear than the gooseneck mirror. This difference was significant in all cases except the right turn at the acute angle junction. This could be considered to be the most difficult permutation of the junction usability task.

1.2.2.2 Validation participants

90° angle junction right turn
The mean ratings of ease of checking the junction is clear for both artificially restricted and validation participants at the 90° angle junction when turning right. It suggests that the patterns of results for the two groups are quite different, and in particular, the observation aids conditions have lower mean ratings than the without devices conditions.

Statistical analysis shows that the ratings given by validation participants in the without devices condition are significantly higher than those given by the artificially restricted participants in the restricted condition ($Z = -2.742, p = 0.006$). This is perhaps to be expected as the validation participants are familiar with this observation method and the results of the junction detection task show that their restriction was not as severe as that imposed by the artificial restriction.

There were no significant differences between the groups for ratings of the junction camera and gooseneck mirror.

Within the artificially restricted group, the observation aids conditions were both rated significantly higher than the restricted condition. Within the validation participants there were no significant differences between the without devices condition and the observation aids conditions.

The validation participant group were consistent with the artificially restricted group in that the junction camera condition was rated significantly higher than the gooseneck mirror condition ($\chi^2 = 4.0, p = 0.046$)

90° angle junction left turn
Again, the ratings of ease of checking given by the validation participants in the without devices condition were significantly higher than those given by the artificially restricted participants ($Z = -2.903, p = 0.004$). There were no significant differences between any of the conditions completed by the validation participants.

Acute angle junction right turn
For the acute angle junction right turn there were no significant differences between the validation and artificially restricted participants and there were no significant differences between conditions within the validation participant group.

Acute angle junction left turn
There were no significant differences between the artificially restricted and validation participants within any condition.
The validation participants were consistent with the artificially restricted participants in that the junction camera was rated significantly higher than the without devices condition ($\chi^2 = 4.0, p = 0.046$) and the junction camera was rated significantly higher than the gooseneck mirror condition ($\chi^2 = 4.0, p = 0.046$). There was no significant difference between the without devices condition and the gooseneck mirror condition, although it can be seen that the gooseneck mirror was rated as worse than no devices by the validation participants and the opposite was true of the artificially restricted participants.

### 1.2.2.3 Ease of checking overall summary

Results from the artificially restricted participants clearly indicated that the junction camera and gooseneck mirror were both easier to use for checking the junction was clear than checking with no devices. However, the ratings for ease of checking using the devices were still lower than those given in the unrestricted condition.

The validation participants tended to rate ease of checking with no aids higher than the artificially restricted participants. This is consistent with the finding from the junction detection test, that the artificially imposed restriction was more limiting than that generally experienced by those with genuine restricted neck and/or trunk movement.

The validation participants tended to agree with the artificially restricted participants that the junction camera made that task of checking the junction easier. Validation participants’ ratings for the gooseneck mirror tended to be lower than ratings given with no devices, although the average position of the ratings on the scale was comparable.

### 1.2.3 Confidence

#### 1.2.3.1 Artificially restricted participants

**Descriptive statistics**

Table 18 shows the mean subjective ratings given in response to the question “How confident or unconfident did you feel using this observation method?” on a ten-point rating scale from 1, “Extremely unsure” to 10, “Extremely confident”. For ease of interpretation the columns for the junction camera and gooseneck mirror conditions are colour coded. The measure is coloured green if participants perceived an improvement (i.e. a more positive rating of confidence) compared to the restricted condition and coloured red if ratings in the device condition were worse on average compared to the restricted condition. Figures shown in brackets below the means indicated the magnitude and direction of the difference between the device conditions and the restricted condition.
### Table 18 Mean ratings of confidence

**Descriptive statistics**

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean rating of confidence (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>90° angle junction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>9.80</td>
<td>2.40</td>
<td>6.00</td>
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<td>(±3.6)</td>
<td></td>
<td></td>
<td>(±1.9)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>0.42</td>
<td>2.07</td>
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<tr>
<td>Left turn</td>
<td>Mean</td>
<td>9.80</td>
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<td>6.90</td>
<td>5.80</td>
</tr>
<tr>
<td></td>
<td>(±4.1)</td>
<td></td>
<td></td>
<td>(±3.0)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
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<td>2.35</td>
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<td>3.05</td>
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</tr>
<tr>
<td>Both combined</td>
<td>Mean</td>
<td>9.80</td>
<td>2.60</td>
<td>6.45</td>
<td>5.05</td>
</tr>
<tr>
<td></td>
<td>(±3.85)</td>
<td></td>
<td></td>
<td>(±2.45)</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
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<td>2.14</td>
<td>1.19</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td><strong>Acute angle junction</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Right turn</td>
<td>Mean</td>
<td>9.70</td>
<td>1.70</td>
<td>6.10</td>
<td>4.60</td>
</tr>
<tr>
<td></td>
<td>(±4.4)</td>
<td></td>
<td></td>
<td>(±2.9)</td>
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</tr>
<tr>
<td>S.D.</td>
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<td>1.89</td>
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<td>3.34</td>
<td></td>
</tr>
<tr>
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</table>

#### 1.2.3.2 Artificially restricted participants

**90° angle junction right turn**

When turning right at the 90° angle junction there was a significant decrease in confidence seen when drivers were restricted and asked to use the aids provided compared to the unrestricted condition:

- Unrestricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Participants reported that they were significantly less confident when restricted. However, more confident when there were aids present:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

Confidence when restricted was significantly higher when using the junction camera and gooseneck mirror:
• Restricted vs. Junction camera ($\chi^2 = 10.0, p = 0.002$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

The difference in confidence score between the junction camera and using the gooseneck mirror approached significance:
• Junction camera vs. Gooseneck ($\chi^2 = 3.6, p = 0.059$)

**90° angle junction left turn**

When turning left at the 90° angle junction there was a significant decrease in confidence seen when restricted and were asked to use the aids provided compared to the unrestricted condition:
• Unrestricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

Participants reported that they were significantly less confident when restricted than when unrestricted.
• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

Confidence when restricted was significantly higher when using the junction camera:
• Restricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)

There were no other significant differences.

**Acute angle junction right turn**

When making a right turn around an acute angle corner, drivers reported that they were less confident when using the aids provided:
• Unrestricted vs. Junction mirror ($\chi^2 = 8.0, p = 0.005$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

Participants also indicated that they became less confident when they were restricted:
• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

When restricted, drivers felt significantly more confident when able to use the aids provided:
• Restricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
• Restricted vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

When comparing the junction camera and the gooseneck mirror, drivers were significantly more confident using the junction camera:
• Junction camera vs. Gooseneck ($\chi^2 = 2.8, p = 0.096$)

No further significant differences were seen.

**Acute angle junction left turn**

When making a left turn around an acute angle corner, drivers reported that they were less confident when using the aids provided:
• Unrestricted vs. Junction mirror ($\chi^2 = 9.0, p = 0.003$)
• Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

Participants also indicated that they became less confident when they were restricted:
• Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

When restricted, drivers felt significantly more confident when able to use the aids provided:
• Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 5.4, p = 0.020$)

When comparing the junction camera and the gooseneck mirror, drivers were significantly more confident using the junction camera:
- Junction camera vs. Gooseneck ($\chi^2 = 5.4, p = 0.020$)

No further significant differences were seen.

**Artificially restricted participants, confidence summary**

There was a significant effect seen when drivers without neck mobility problems were artificially restricted. This is to be expected and it resulted in a large decrease in their quality of view at junctions. Drivers, when artificially restricted, preferred using the junction camera rather than the gooseneck mirror on all junctions. The improvement in confidence was again to be expected as the drivers are unaccustomed to driving with restricted head movement.

Although there was an increase in the unrestricted drivers confidence when using any one of the aids available, their confidence levels were still significantly decreased from the levels seen when driving freely.

When further examining the unrestricted driver group, there were some interesting findings when they restricted and asked to use the aids. There was a significant difference seen between the two aids at an acute junction turn, with the junction camera being the aids that give the most confidence.
### Validation participants

**Table 19 Descriptive statistics**

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean rating of confidence (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
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<td></td>
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</table>

**90° angle junction right turn**

There was a significant difference decrease in confidence when drivers were asked to turn right at a 90° angle junction while using the gooseneck mirror:

- Restricted vs. Gooseneck mirror ($\chi^2 = 4.0$, p = 0.046)

Drivers were significantly more confident when using the junction camera compared to the gooseneck mirror:

- Junction camera vs. Gooseneck mirror ($\chi^2 = 4.0$, p = 0.046)

No further significant results were found

**90° angle junction left turn**

Once again, when turning left at the same 90° angle junction, drivers were significantly less confident using the gooseneck mirror:
• Restricted vs. Gooseneck mirror ($\chi^2 = 4.0$, $p = 0.046$)

Confidence was significantly greater when using the junction camera to negotiate the left turn, compared to the same turn using the gooseneck mirror:

• Junction camera vs. Gooseneck mirror ($\chi^2 = 4.0$, $p = 0.046$)

There were no further significant differences

**Acute angle junction right turn**

There was an increase in confidence of drivers turning right at an acute angle junction using the junction camera, but it failed to reach significance:

• Restricted vs. Junction camera ($\chi^2 = 0.33$, $p = 0.564$)

There were no further significant results

**Acute angle junction left turn**

Drivers were significantly more confident when turning left at an acute junction when they used the junction camera:

• Restricted vs. Junction camera ($\chi^2 = 4.0$, $p = 0.046$)

There was a decrease in driver confidence when using the gooseneck mirror at the same junction, but neared significance:

• Restricted vs. Gooseneck mirror ($\chi^2 = 3.0$, $p = 0.083$)

Overall, drivers were significantly more confident turning left at the junction when they used the junction camera aid:

• Junction camera vs. Gooseneck mirror ($\chi^2 = 4.0$, $p = 0.046$)

There were no further significant differences

**Validation participants, Confidence overall summary**

Due to the variability of the confidence ratings reported by drivers, it is hard to assess the significance of any changes in the average confidence scores seen in this group. This may be due, in part, to the small numbers of validation participants that were able to take part in the study. The validation group actually felt that their quality of view at 90° junctions was better when unaided, with the gooseneck mirror being quiet disruptive. However, when examining acute angle junctions, the validation group felt that there was an improvement in their confidence when using the junction camera. The results indicate that validation participants found the gooseneck mirror unhelpful at acute angle junctions and again thought it decreased the confidence when turning at that type of junction.

There was a large difference in the confidence levels when comparing drivers that had a decrease in neck mobility, and those drivers that had been artificially restricted. There was a general pattern of a significant decrease in confidence seen in the artificially restricted group, however the validation group were much more confidant in comparison. Where drivers who were artificially restricted saw their confidence increase when either aid was available, the validation group experienced a split. The validation group experienced a significant decrease in their confidence when using the gooseneck mirror. However, when their used the junction camera they were more confident that if they had been driving unaided.
1.2.4 Quality of view

1.2.4.1 Artificially restricted participants

Table 20 Descriptive statistics

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Mean rating of quality of view (2 d.p.)</th>
<th>Unr</th>
<th>R</th>
<th>JC</th>
<th>GM</th>
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<tbody>
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<td>90° angle junction</td>
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<td>Mean</td>
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<td>7.29</td>
<td>1.46</td>
<td>0.93</td>
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</table>

90° angle junction right turn

There was a significant difference in the quality of view reported by driver turning right at a 90° angle junction when the restriction was in place:
- Unrestricted vs. Restricted ($\chi^2 = 10.0$, $p = 0.002$)

When turning right at the 90° angle junction there was a significant decrease in quality of view that drivers had even with the aids provided:
- Unrestricted vs. Junction camera ($\chi^2 = 10.0$, $p = 0.002$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 6.40$, $p = 0.011$)

There was a significant increase in the quality of view when restricted drivers used the junction camera:
- Restricted vs. Junction camera ($\chi^2 = 10.0$, $p = 0.002$)
There was a significantly better quality of view provided by the junction camera compared to the gooseneck mirror:

- Junction camera vs. Gooseneck mirror ($\chi^2 = 6.4, p = 0.011$)

There were no further significant differences.

**90° angle junction left turn**

There was a significant difference in the quality of view reported by drivers turning left at a 90° angle junction when the restriction was in place:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

When turning left at the 90° angle junction there was a significant decrease in quality of view that drivers had even with the aids provided:

- Unrestricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 9.0, p = 0.003$)

There was a significant increase in the quality of view when restricted drivers used the junction camera:

- Restricted vs. Junction camera ($\chi^2 = 8.0, p = 0.005$)

There were no further significant differences.

**Acute angle junction right turn**

There was a significant difference in the quality of view reported by drivers turning right at an acute angle junction when the restriction was in place:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

When turning right at the acute angle junction there was a significant decrease in quality of view that drivers had even with the aids provided:

- Unrestricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 8.0, p = 0.005$)

There was a significant increase in the quality of view when restricted drivers used the junction camera at the acute angle junction. There was also a small, but significant difference in the quality of view when the driver used the gooseneck mirror at the same junction:

- Restricted vs. Junction camera ($\chi^2 = 4.5, p = 0.034$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 4.5, p = 0.034$)

**Acute angle junction left turn**

There was a significant difference in the quality of view reported by drivers turning left at an acute angle junction when the restriction was in place:

- Unrestricted vs. Restricted ($\chi^2 = 10.0, p = 0.002$)

When turning left at the acute angle junction there was a significant decrease in quality of view that drivers had even with the aids provided:

- Unrestricted vs. Junction camera ($\chi^2 = 5.4, p = 0.020$)
- Unrestricted vs. Gooseneck mirror ($\chi^2 = 10.0, p = 0.002$)

There was a significant increase in the quality of view when restricted drivers used the junction camera at the acute angle junction. There was also a small, but significant difference in the quality of view when the driver used the gooseneck mirror at the same junction:

- Restricted vs. Junction camera ($\chi^2 = 6.4, p = 0.011$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 4.5$, $p = 0.034$)

The junction camera gives a better quality of view at the left hand junction compared to the gooseneck mirror, and although the difference was not significant it was approaching so:
- Junction camera vs. Gooseneck mirror ($\chi^2 = 3.6$, $p = 0.058$)

**Artificially restricted participants, quality of view summary**

When examining confidence drivers felt at different junctions it became clear that there was a similar pattern to that seen when drivers were asked to rate the quality of the view. Drivers that were artificially restricted felt less confident when the restriction was imposed on them. However, they found both aids helpful at 90° junctions and acute angle junctions. When examined closer, it was clear that the junction camera was the preferred aid by these drivers. This was the case in both left and right junctions and when the data was combined and examined.

There was a similar pattern seen in the drivers rating for the quality of view compared to their confidence. Again, was a large difference in the quality of view ratings when comparing drivers that had a decrease in neck mobility, and those who had been artificially restricted. There was a general pattern of a significant decrease in the quality of view when the artificially restricted group were turning (regardless of type of junction). However the validation group were much more satisfied with their quality of view in comparison. When artificially restricted, the drivers’ quality of view increased regardless of which aid they used. The junction camera produced more significant increases in view quality, but the gooseneck mirror also increased confidence (this was not the case in the validation group).
1.2.4.2 Validation participants

Table 21 Descriptive statistics

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<td>R</td>
<td>JC</td>
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<td></td>
<td>S.D.</td>
<td>0.00</td>
<td>3.40</td>
<td>3.01</td>
<td>2.43</td>
</tr>
<tr>
<td>All combined</td>
<td>Mean</td>
<td>0.00</td>
<td>6.63</td>
<td>7.00</td>
<td>2.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(+0.37)</td>
<td>(-3.94)</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.00</td>
<td>2.15</td>
<td>2.19</td>
<td>2.88</td>
</tr>
</tbody>
</table>

90° angle junction right turn

There was a significant decrease in the quality of view when drivers were asked to turn right at a 90° angle junction while using the gooseneck mirror:

- Restricted vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

Even though there was a decrease in the quality of view when drivers used the junction camera it was significantly better that when using the gooseneck mirror:

- Junction camera vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

No further significant results were found.
90° angle junction left turn

There was a significant decrease in the quality of view when drivers were asked to turn left at a 90° angle junction while using the gooseneck mirror:

- Restricted vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

Even though there was a decrease in the quality of view when drivers used the junction camera it was significantly better that when using the gooseneck mirror:

- Junction camera vs. Gooseneck mirror ($\chi^2 = 4.0, p = 0.046$)

No further significant results were found.

Acute angle junction right turn

There was no significant difference in quality of view when turning right at an acute junction using either of the aids available:

- Restricted vs. Junction camera ($\chi^2 = 0.33, p = 0.564$)
- Restricted vs. Gooseneck mirror ($\chi^2 = 2.00, p = 0.157$)

There was also no significant difference in the quality of view given when comparing the two aids to each other:

- Junction camera vs. Gooseneck mirror ($\chi^2 = 2.00, p = 0.157$)

Acute angle junction left turn

When drivers turned left at an acute angle junction, the quality of view was significantly increased when using the junction camera:

- Restricted vs. Junction camera ($\chi^2 = 4.0, p = 0.046$)

There was also a significant better quality of view given by the junction camera compared to the gooseneck camera when turning left at the junction:

- Junction camera vs. Gooseneck camera ($\chi^2 = 4.0, p = 0.046$)

No further significant results were found.

Validation participants, Quality of view overall summary

Drivers with neck mobility problems felt their quality of view was better when unaided at a 90° angle junction. This is a surprising finding, with the goose neck mirror actually producing a significant decrease in the quality of view at a 90° junction. This suggests that the aids are actually a hindrance when used at this type of junction.

In comparison, drivers that were artificially restricted found the aids increased their quality of view at these junctions. The results were similar, but with a much lower quality of view experienced by the artificially restricted drivers when no aids were available.

However, when the validation group used the same aids at an acute angle junction they found the junction camera significantly increased the quality of view available. The largest difference was seen at a left hand turn on an acute junction. When turning right at an acute junction, there was a slight increase in the view quality when using the junction camera. This was significantly different from the assistance provided by the gooseneck mirror, which actually reduced the quality of view when used at the same right hand turn. These results where comparable to those of the artificially restricted drivers in turns of mean rating of view.
quality. However, the artificially restricted group again had a much lower rating under the control condition and both aids were helpful in increasing their quality of view. The two groups vary on the usefulness of the gooseneck mirror at this type of junction, with unrestricted finding the aid helpful and the validation believing it reduced the quality of their view.

I.3 Reverse parking

Subjective comments and observations of user behaviour and usability issues were also recorded. Analysis of this data is reported in section

Analysis of each measure is presented in the following sections for both groups of participants; the artificially restricted group and the validation group.

I.3.1 Time taken

This section described the findings of the time taken to complete the reverse parking task comparison between observation conditions for the ten artificially restricted participants for each permutation studied. Unless otherwise stated, all analyses in this section were conducted using a series of Friedman tests to examine the pairs:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

I.3.1.1 Artificially restricted participants

Descriptive Statistics

Table 22 shows the mean and standard deviation of the time taken to complete the reverse park under the various observation conditions. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. faster park time) compared with the Restricted condition and coloured red if there was a if the task took longer in the device conditions when compared with the Restricted condition. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.
Table 22 Mean time (seconds) taken to complete the task, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean time (seconds) to complete the task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 28.07</td>
</tr>
<tr>
<td></td>
<td>S.D. 15.455</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 37.03</td>
</tr>
<tr>
<td></td>
<td>S.D. 21.708</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 42.24 (+5.21)</td>
</tr>
<tr>
<td></td>
<td>S.D. 24.350</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 67.73 (+30.7)</td>
</tr>
<tr>
<td></td>
<td>S.D. 66.295</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 58.71 (+21.68)</td>
</tr>
<tr>
<td></td>
<td>S.D. 63.293</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 55.66 (+18.63)</td>
</tr>
<tr>
<td></td>
<td>S.D. 58.119</td>
</tr>
</tbody>
</table>

The descriptive statistics show that the artificially restricted participants completed the reverse park most quickly in the unrestricted condition on all occasions. The average time taken to complete the reverse park was higher in all device conditions compared with the restricted condition.

The comparison between the restricted vs. unrestricted conditions for time taken to complete the reversing task was approaching significance; it took longer to complete the task in the restricted condition than in the unrestricted condition:

- Restricted vs. Unrestricted ($\chi^2 = 3.600$, $p = 0.058$)

When comparing all device conditions (separately) to the Restricted condition, there were significant differences in the time taken to complete the task for two pairs:

- Visual sensor vs. Restricted ($\chi^2 = 6.400$, $p = 0.011$)
- Audible sensor vs. Restricted ($\chi^2 = 6.400$, $p = 0.011$)

These comparisons showed that it took significantly longer to complete the reverse parking task in the visual and audible sensor conditions than in the restricted condition. There was no significant difference between the time taken to complete the task between the Reversing camera condition and the restricted condition or the panoramic mirror condition and the restricted condition. These findings reject the original hypothesis that participants would take a significantly shorter time to complete the reversing task in the device conditions than in the restricted condition.

When comparing all of the devices with each other, there was only one pair where a significant difference was observed; it took significantly longer to complete the reverse parking task in the visual sensor condition than it did in the panoramic mirror condition:

- Visual sensor vs. Panoramic mirror ($\chi^2 = 9.000$, $p = 0.003$)

When comparing each of the device conditions with the unrestricted condition, it took significantly longer to complete the reverse parking task in the visual sensor, audible sensor and panoramic mirror conditions compared with the unrestricted condition:

- Visual sensor vs. Unrestricted ($\chi^2 = 10.000$, $p = 0.002$)
• Audible sensor vs. Unrestricted ($\chi^2 = 10.000, p = 0.002$)
• Panoramic mirror vs. Unrestricted ($\chi^2 = 6.4000, p = 0.011$)

When the Reversing Camera was compared with the unrestricted condition, the comparison approached significance:
• Reversing camera vs. Unrestricted ($\chi^2 = 3.600, p = 0.058$)

1.3.1.2 Validation participants
The validation participants’ times in the without devices condition tended to be faster than the artificially restricted participants’ times in the restricted condition. However, these differences were not significant.

This indicates that the two groups were broadly comparable in terms of the time taken to complete the reverse park task and that the restricted condition was a valid approximation of people with restricted movement for this measure.

Table 22 shows the mean time taken for both participant groups to complete the reverse park; validation participants completed the task fastest in the without device condition and slowest in the reversing camera condition. When the devices were compared with the without device conditions in the validation phase, it took significantly longer in the visual sensor and panoramic mirror conditions than it did in the without device condition:
• Visual sensor vs. Without device ($\chi^2 = 4.000, p = 0.046$)
• Panoramic mirror vs. Without device ($\chi^2 = 4.000, p = 0.046$)

However, when the devices were compared with each other, there were no significantly different pairs.

1.3.2 Critical Exceedances
This section examines the differences between the number of critical exceedances (e.g. crossing the line or touching a cone) made during the task between conditions for the ten artificially restricted participants for each of the permutations.

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted
1.3.2.1 Artificially restricted participants

Descriptive Statistics

Table 23 shows the mean and standard deviation of the number of critical exceedances made the reverse park task under the various observation conditions. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. fewer critical exceedances) compared with the restricted condition and coloured red if there was a if the task more critical exceedances were made in the device conditions when compared with the restricted condition (the measure is coloured blue if the difference is smaller than 0.5 critical exceedances). Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean number of critical exceedances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 0.5</td>
</tr>
<tr>
<td></td>
<td>S.D. 0.707</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 1.1</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.595</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 1.0 (-0.1)</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.155</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 1.2 (+0.1)</td>
</tr>
<tr>
<td></td>
<td>S.D. 0.632</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 2.0 (+0.9)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.906</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 1.9 (+0.8)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.079</td>
</tr>
</tbody>
</table>

The descriptive statistics show that the fewest critical exceedances were made in the unrestricted condition and the most were made in the panoramic mirror condition. Fewer critical exceedances were made in the reversing camera condition than in the restricted condition, but this difference was not significant.

No significant difference was found between the number of critical exceedances made in the restricted condition compared with the unrestricted condition. This finding rejects the original hypothesis that participants would make significantly more critical exceedances in the restricted condition than in the unrestricted condition.

When comparing the number of critical exceedances made in all of the device conditions with the restricted condition, there were no significant differences in the number of critical exceedances made by the participants.

When all of the devices were compared (separately) with each other, again, no significant differences were found between any of the pairs.

However, a difference approaching significance was found between the number of critical exceedances made in the comparison of the visual sensor and the unrestricted condition; more
critical exceedances were recorded in the Visual sensor condition than in the unrestricted condition:

- Visual sensor vs. Unrestricted \( (\chi^2 = 3.571, p = 0.059) \)

This finding is not surprising given that the unrestricted condition was the most familiar and practiced condition.

### I.3.2.2 Validation participants

The validation group made, on average, fewer critical exceedances than the artificially restricted participants, but this difference was not significant. This suggests that the two participant groups were well matched for this measure. The validation participants made the most critical exceedances in the without device and audible sensor conditions, while the artificially restricted participants made the most critical exceedances in the audible sensor condition. Fewest critical exceedances were made in the visual sensor condition, suggesting that this and the reversing camera condition may be useful parking aids for restricted drivers as they produced better results than those with no devices at all.

When the devices were compared with the without device condition in the validation phase, there were no significantly different pairs. Nor were there any significantly different pairs when the device conditions were compared with one another.

### I.3.3 Quality

This section looks at the differences between the perceived quality-ratings of the reverse parks for between conditions for the ten artificially restricted participants for each of the permutations studied:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

Table 24 shows the mean and standard deviation of the ratings of quality of the reverse parks as judged by external raters. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. a better quality rating) compared with the Restricted condition and coloured red if the quality rating was lower than that of Restricted condition (the measure is coloured blue if the rating difference is smaller than 0.5). Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.
Table 24 Mean quality rating, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean quality rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 5.63</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.134</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 4.63</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.134</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 5.00 (+0.37)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.268</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 4.00 (-0.63)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.070</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 5.25 (+0.62)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.252</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 4.5 (-0.13)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.330</td>
</tr>
</tbody>
</table>

For the artificially restricted participants, the comparisons of the perceived quality of the reverse park revealed no significantly different pairs. A similar pattern was found for the validation participants, when the devices were compared to the Without Device condition in the validation phase, there were no significantly different pairs. Nor were there any significantly different pairs when the device conditions were compared with one another.

### 1.3.4 Ease of reversing

#### Descriptive Statistics

This section looks at the differences between the mean ratings of ease of reversing between conditions for the ten artificially restricted participants for each of the permutations studied:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

#### I.3.4.1 Artificially restricted participants

Table 25 shows the mean and standard deviation of the ratings of how easy or difficult the participants found task completion. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. the
task was easier) compared with the Restricted condition and coloured red if the task was harder than that of Restricted condition. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

### Table 25 Mean ease of reversing rating, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean ease of reversing rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unrestricted</strong></td>
<td>Mean 8.7, S.D. 1.059</td>
</tr>
<tr>
<td><strong>Restricted</strong></td>
<td>Mean 5.4, S.D. 2.591</td>
</tr>
<tr>
<td><strong>Reversing camera</strong></td>
<td>Mean 6.2 (+0.8), S.D. 2.348</td>
</tr>
<tr>
<td><strong>Visual sensor</strong></td>
<td>Mean 4.7 (-0.7), S.D. 2.669</td>
</tr>
<tr>
<td><strong>Audible sensor</strong></td>
<td>Mean 4.9 (-0.5), S.D. 2.961</td>
</tr>
<tr>
<td><strong>Panoramic mirror</strong></td>
<td>Mean 4.1 (-1.3), S.D. 2.424</td>
</tr>
</tbody>
</table>

The artificially restricted participants found the reversing task to be easiest in the unrestricted condition and most difficult in the panoramic mirror condition. The only device which appeared to make the task easier than it was in the restricted condition was the reversing camera, but the difference was not significant.

Unsurprisingly, the results show that it was significantly easier to reverse into the space in the unrestricted condition than it was in the restricted condition:

- Restricted vs. Unrestricted ($\chi^2 = 10.000, p = 0.002$)

There were no significant differences between any of the devices paired with the restricted condition in terms of how easy the participant found it to complete the task.

When comparing device conditions with other device conditions, there was a difference which approached significance in the perceived ease of reverse parking for one pair of devices; the Visual sensor compared with the audible sensor. It was easier to complete the task in the audible sensor condition than it was in the visual sensor condition:

- Audible sensor vs. Visual sensor ($\chi^2 = 3.571, p = 0.059$)

When comparing each of the device conditions with the unrestricted condition, it was considered significantly easier to complete the reverse parking task in the unrestricted condition compared with all device conditions:

- Unrestricted vs. Reversing camera ($\chi^2 = 5.444, p = 0.020$)
- Unrestricted vs. Visual sensor ($\chi^2 = 10.000, p = 0.002$)
- Unrestricted vs. Audible sensor ($\chi^2 = 9.000, p = 0.003$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 10.000, p = 0.002$)

The results show that none of the devices compensated to the level of the unrestricted driver for this measure; in fact, none of the devices compared significantly with the level of a restricted driver.
I.3.4.2 Validation participants

When the devices were (separately) compared with the without device condition, only one significantly different pair was found; the results show that the validation participants found the reverse parking task significantly easier in the without device condition than they did in the panoramic mirror condition ($\chi^2 = 4.000, p = 0.046$). This suggests that the panoramic mirror does nothing to compensate for the validation participants’ restricted movement.

When the devices were compared with one another for how easy the validation participants found completing the reversing task, it was found that the reversing camera condition made the task significantly easier than the audible sensor and the panoramic mirror conditions for the validation participants:
- Reversing Camera vs. Audible Sensor ($\chi^2 = 4.000, p = 0.046$)
- Reversing Camera vs. Panoramic Mirror ($\chi^2 = 4.000, p = 0.046$)

It was also found that the reverse park was considered to be significantly easier in the visual sensor condition than it was in the panoramic mirror condition:
- Visual Sensor vs. Panoramic Mirror ($\chi^2 = 4.000, p = 0.046$)

The difference between the ease of reversing between the audible sensor and the panoramic mirror conditions approached significance; it was easier to complete the task in the audible sensor condition than in the panoramic mirror condition:
- Audible sensor vs. Panoramic mirror ($\chi^2 = 3.000, p = 0.083$)

These findings suggest that the panoramic mirror is the device which is least helpful in compensating for impaired function, it has, in fact been found to make the task more difficult than it was with no devices at all.

I.3.4.3 Confidence

This section looks at the differences between the mean ratings of confidence between conditions for the ten artificially restricted participants for each of the permutations studied:
1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

I.3.4.4 Artificially restricted participants

Table 26 shows the mean and standard deviation of the ratings of participant confidence. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. the confidence rating was higher) compared with the restricted condition and coloured red if the confidence rating was lower than that of restricted condition. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.
Table 26 Mean Confidence Ratings

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean confidence of reversing rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>8.9</td>
</tr>
<tr>
<td>Restricted</td>
<td>5.5</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>5.7 (+0.2)</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>4.3 (-1.2)</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>4.8 (-0.7)</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>4.5 (-1)</td>
</tr>
</tbody>
</table>

Table 26 shows that the artificially restricted participants felt most confident in the unrestricted condition and least confident in the panoramic mirror condition. The only device which was found to increase confidence from the restricted baseline was the reversing camera; however, this difference was not significant. All of the other devices reduced the artificially restricted participants’ confidence to below the restricted ratings.

Participants rated themselves as feeling significantly more confident in the unrestricted condition than in the restricted conditions:
- Unrestricted vs. Restricted ($\chi^2 = 10.000, p = 0.002$)

When all device conditions were compared with the restricted condition for confidence ratings, there were no significantly different pairs.

Comparison of the device conditions with other device conditions revealed one significant pair; artificially restricted participants felt significantly more confident in the reversing camera condition than they did in the visual sensor condition:
- Reversing camera vs. Visual sensor ($\chi^2 = 5.444, p = 0.020$)

The audible sensor was also rated as giving more confidence than the visual sensor, this difference approached significance:
- Audible sensor vs. visual Sensor ($\chi^2 = 3.571, p = 0.059$)

When comparing the unrestricted condition with all of the device conditions separately, higher confidence ratings were given in the unrestricted condition than all other conditions:
- Unrestricted vs. Reversing camera ($\chi^2 = 9.000, p = 0.003$)
- Unrestricted vs. Visual sensor ($\chi^2 = 10.000, p = 0.002$)
- Unrestricted vs. Audible sensor ($\chi^2 = 9.000, p = 0.003$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 10.000, p = 0.002$)

These findings show that none of the devices compensate to the level of an unrestricted driver in how confident they make the driver feel; nor do they compensate to the level of the artificially restriction placed upon participants.
I.3.4.5 Validation participants

Validation participants appeared to feel more confident using the reversing camera, and least confident using the panoramic mirror, in fact, the panoramic mirror provided validation participants with lower confidence ratings than any other device. When the devices were compared (separately) to the without device condition, there were no significantly different pairs. When the devices were compared with each other in terms of confidence ratings provided by the validation participants, there were four different pairs which approached significance:

- Reversing camera vs. Audible sensor ($\chi^2 = 3.000$, $p = 0.083$)
- Reversing camera vs. Panoramic mirror ($\chi^2 = 3.000$, $p = 0.083$)
- Visual sensor vs. Panoramic mirror ($\chi^2 = 3.000$, $p = 0.083$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 3.000$, $p = 0.083$)

These findings show that while the reversing camera increased the validation participants’ confidence, the difference in confidence between the without device condition and the reversing camera was bit significant; on the basis of these findings, drivers with restricted neck and trunk function would feel just as confident reverse parking with no devices as they would with the reversing camera system. However, confidence ratings might increase with practice and familiarisation with the device.

I.3.5 Helpfulness

This section describes the results of the comparisons of how helpful or unhelpful the artificially restricted participants rated the devices for helping them to complete the task. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Reversing camera vs. Visual sensor
2. Reversing camera vs. Audible sensor
3. Reversing camera vs. Panoramic mirror
4. Visual sensor vs. Audible sensor
5. Visual sensor vs. Panoramic mirror
6. Audible sensor vs. Panoramic mirror

Table 27 shows the mean and standard deviations of the artificially restricted participants’ ratings of device helpfulness. For ease of interpretation, the helpfulness column is colour-coded. The least helpful device is coloured red and the most helpful device is coloured green.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean helpfulness ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversing camera</td>
<td>Mean 6.6, S.D. 2.221</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 5.5, S.D. 2.593</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 6.8, S.D. 2.700</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 1.8, S.D. 1.476</td>
</tr>
</tbody>
</table>
I.3.5.1 Artificially restricted participants

As seen in Table 27 above, the audible sensor was considered to be the most helpful device (mean=6.8); the panoramic mirror was considered to be the least helpful device (mean=1.8). When comparing the devices with each other for helpfulness, the panoramic mirror was rated as being the least helpful of all of the devices for this task; all of the other devices were rated as being significantly more helpful than the panoramic mirror:

- Reversing camera vs. Panoramic mirror ($\chi^2 = 6.400, p = 0.011$)
- Visual sensor vs. Panoramic mirror ($\chi^2 = 8.000, p = 0.005$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 9.000, p = 0.003$)

It is not surprising that the panoramic mirror was considered to be the least helpful device; the view is provides is very similar to that of a standard rear view mirror, so participants are not really gaining much assistance from its use.

I.3.5.2 Validation participants

When the device conditions were separately compared with each other for the perceived helpfulness, there were three significant pairs; the reversing camera condition was rated as being significantly more helpful than the visual sensor and panoramic mirror conditions, the audible sensor was also rated as being significantly more helpful than the panoramic mirror:

- Reversing camera vs. Audible sensor ($\chi^2 = 4.000, p = 0.046$)
- Reversing camera vs. Panoramic mirror ($\chi^2 = 4.000, p = 0.046$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 4.000, p = 0.046$)

The difference between the audible sensor and the panoramic mirror conditions approached significance:

- Audible sensor vs. Panoramic mirror ($\chi^2 = 3.000, p = 0.083$)

These findings, like those from the artificially restricted participants’ data, show the panoramic mirror to be the least helpful device.

I.3.6 Reliance on aid-only for aid conditions

This section describes the results of the comparisons of how much the artificially restricted participants relied on the devices to complete the task. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Reversing camera vs. Visual sensor
2. Reversing camera vs. Audible sensor
3. Reversing camera vs. Panoramic mirror
4. Visual sensor vs. Audible sensor
5. Visual sensor vs. Panoramic mirror
6. Audible sensor vs. Panoramic mirror
Table 28 Mean rating of reliance on devices, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean reliance rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversing camera</td>
<td>Mean 7.5 S.D. 2.506</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 6.2 S.D. 3.048</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 8.0 S.D. 1.414</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 2.0 S.D. 1.633</td>
</tr>
</tbody>
</table>

I.3.6.1 Artificially restricted participants

As shown in Table 28, for the artificially restricted participants, the Audible sensor was most relied upon device (mean=8.0); the panoramic mirror was the device rated as being relied on the least (mean=2.0).

When comparing the devices with each other for reliance, the panoramic mirror was rated as being the least helpful of all of the devices for this task; all of the other devices were rated as being significantly more relied upon than the panoramic mirror:

- Reversing camera vs. Panoramic mirror ($\chi^2 =10.000$, $p =0.002$)
- Visual sensor vs. Panoramic mirror ($\chi^2 =9.000$, $p =0.003$)
- Audible sensor vs. Panoramic mirror ($\chi^2 =9.000$, $p =0.003$)

12.1.1 Validation participants

The validation participants, like the artificially restricted participants, rated the reversing camera as being the most relied upon device; the panoramic mirror was rated as being the least relied upon device.

The validation participants rated themselves as relying significantly more on the audible sensor than on the panoramic mirror:

- Audible sensor vs. Panoramic mirror ($\chi^2 =4.000$, $p =0.046$)

The findings from the both groups for this measure suggest that a panoramic mirror may not be the most helpful device for helping restricted drivers to perform reverse parking manoeuvres compared with other devices available on the market.
I.4 Turn in the road

Subjective comments and observations of user behaviour and usability issues were also recorded. Analysis of each measure is presented in the following sections for both groups of participants; the artificially restricted group and the validation group.

I.4.1 Time

This section describes the results of the comparisons of time taken to complete the turn in the road between observation conditions for the artificially restricted participants. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

Descriptive Statistics

Table 29 shows the mean and standard deviation of the time taken for the participants to complete the turn in the road. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. the time was faster) compared with the restricted condition and coloured red if the time was slower than that of restricted condition. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean time taken (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 28.38 S.D. 3.841</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 28.84 S.D. 5.777</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 32.75 (+3.91) S.D. 7.534</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 34.4 (+5.56) S.D. 7.539</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 33.01 (+4.17) S.D. 6.013</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 36.37 (+7.35) S.D. 8.340</td>
</tr>
</tbody>
</table>
I.4.1.1  Artificially restricted participants

As shown in Table 29 above, the time taken to complete the turn in the road was higher in all of the device conditions than it was in the unrestricted condition. There was no significant difference between the times taken to complete the turn in the road in the restricted condition compared with the unrestricted condition. The restricted time was lower than expected, this may be because the artificial restriction may have allowed participants to move their head more than they were instructed to.

When all device conditions were compared separately with the restricted condition, it took longer to complete the task in the reversing camera and visual sensor conditions than it did in the restricted condition without devices:
- Restricted vs. Reversing camera ($\chi^2 = 6.4, p = 0.011$)
- Restricted vs. Visual sensor ($\chi^2 = 4.500, p = 0.034$)

The comparison between the restricted and panoramic mirror conditions was approaching significance:
- Restricted vs. Panoramic mirror ($\chi^2 = 2.778, p = 0.096$)

When comparing the devices with each other, there were no significant differences between pairs of devices and the time taken to complete the turn in the road.

Comparing the devices to the unrestricted condition, it was found that the mean time taken to complete the turn in the unrestricted condition was significantly lower in the unrestricted condition than in the audible sensor condition:
- Unrestricted vs. Audible sensor ($\chi^2 = 5.444, p = 0.020$)
- Unrestricted vs. Reversing camera ($\chi^2 = 3.600, p = 0.058$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 3.600, p = 0.058$)

I.4.1.2  Validation participants

For the validation participants, the task took longest to complete in the visual sensor condition and least time in the reversing camera condition. When the without device condition was compared with the different device conditions for this measure, there were no significantly different pairs. However, when devices were compared with each other, it was found that it took significantly longer to complete the task in the panoramic mirror condition than it did in the reversing camera condition:
- Panoramic mirror vs. Reversing camera ($\chi^2 = 4.000, p = 0.046$)

In general, the validation participants completed the turn in the road slower than the artificially restricted participants did, but this difference was not significant.

I.4.2  Percentage of Flashes seen

This section describes the results of the comparisons of percentage of flashes seen by the artificially restricted participants as they completed the turn in the road between observation conditions. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:
1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

**Descriptive Statistics**

Table 30 shows the mean and standard deviation of the percentage of flashes seen by the participants while making the turn in the road. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. the participants saw a higher percentage of flashes) compared with the restricted condition and coloured red if fewer flashes were seen than there were in restricted condition. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

Table 30 Mean percentage of flashes seen by participants while completing the turn in the road, artificially restricted participants.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean percentage of flashes seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 47.60</td>
</tr>
<tr>
<td></td>
<td>S.D. 17.539</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 35.00</td>
</tr>
<tr>
<td></td>
<td>S.D. 21.328</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 26.9 (-8.1)</td>
</tr>
<tr>
<td></td>
<td>S.D. 11.986</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 29.00 (-6)</td>
</tr>
<tr>
<td></td>
<td>S.D. 15.818</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 28.70 (-6.3)</td>
</tr>
<tr>
<td></td>
<td>S.D. 15.085</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 36.40 (+1.4)</td>
</tr>
<tr>
<td></td>
<td>S.D. 18.404</td>
</tr>
</tbody>
</table>

**I.4.2.1 Artificially restricted participants**

Table 30 above shows that artificially restricted participants saw fewer flashes in the reversing camera, visual sensor and audible sensor conditions than they did in the restricted condition. The table also shows that the participants saw 1.4% more flashes in the panoramic mirror condition than in the restricted condition.

When the comparison was made between the percentage of flashes seen for the restricted and unrestricted conditions, artificially restricted participants saw a higher percentage of flashes in
the unrestricted condition than they did in the restricted condition, this difference approached significance:

- Unrestricted vs. Restricted ($\chi^2 = 3.600, p = 0.058$)

Each of the devices were (separately) compared with the restricted condition, when these comparisons were made, there were no significantly different pairs.

Friedman tests were carried out on device conditions compared with other device conditions; no significant differences were found, however, the following pairs approached significance:

- Visual sensor vs. Panoramic mirror ($\chi^2 = 3.600, p = 0.058$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 3.600, p = 0.058$)

When all device conditions were compared with the unrestricted condition, a significantly higher percentage of flashes were seen in the unrestricted condition than in the visual and audible sensor conditions and the panoramic mirror condition:

- Unrestricted vs. Visual sensor ($\chi^2 = 10.000, p = 0.002$)
- Unrestricted vs. Audible sensor ($\chi^2 = 6.400, p = 0.011$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 5.444, p = 0.020$)

The comparison between the unrestricted and reversing camera conditions approached significance:

- Unrestricted vs. Reversing camera ($\chi^2 = 2.778, p = 0.096$)

I.4.2.2 Validation participants

The validation participants saw the highest percentage of flashes in the reversing camera condition and fewest flashes in the visual sensor condition. For the validation participants, there were no significantly different pairs when the without device condition was compared with the device conditions. When the device conditions were compared with each other, there were two pairs which approached significance, there were more flashes seen in the reversing camera condition than there were in the audible sensor and panoramic mirror conditions:

- Reversing camera vs. Audible sensor ($\chi^2 = 3.000, p = 0.083$)
- Reversing camera vs. Panoramic mirror ($\chi^2 = 3.000, p = 0.083$)

This was a surprising finding as it was expected that the screen may act as a distraction given that the reversing camera system is designed for drivers to look at a screen.

I.4.3 Ease of turn

This section describes the results of the comparisons of how easy or difficult the artificially restricted participants rated the task between observation conditions. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

Table 31 shows the mean and standard deviation of the rating of ease of task completion. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured green if there was an improvement (i.e. the participants rated the task as being easier) compared with the restricted condition and coloured red if the task was rated as being more difficult to complete than in restricted condition. Measures are coloured blue if the difference was a rating lower than 0.5. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

Table 31 Mean rating of ease for completion of the task, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean rating of ease for completion of the task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 8.9</td>
</tr>
<tr>
<td></td>
<td>S.D. 0.876</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 6.9</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.449</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 7.6 (+0.7)</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.955</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 6.7 (-0.2)</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.003</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 7.5 (+0.6)</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.179</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 5.9 (-1)</td>
</tr>
<tr>
<td></td>
<td>S.D. 1.729</td>
</tr>
</tbody>
</table>

I.4.3.1 Artificially restricted participants

Table 31 shows that for the artificially restricted participants, rated ease of completion of the task higher in the reversing camera and audible sensor conditions than in the restricted condition. The rating was slightly lower in the visual sensor than in the restricted condition, and was lowest in the panoramic mirror condition.

The artificially restricted participants found it significantly easier to perform the turn in the road in the unrestricted condition than in the restricted condition:

- Unrestricted vs. Restricted ($\chi^2 = 8.000$, p = 0.005)

When all device conditions were compared separately with the restricted conditions, participants considered, performing the turn in the restricted condition was considered to be significantly easier than in the panoramic mirror condition:

- Restricted vs. Panoramic mirror ($\chi^2 = 5.000$, p = 0.025)
The comparison between ease of task in the reversing camera and restricted conditions, approached significance:

- Reversing camera vs. Restricted ($\chi^2 = 2.778, p = 0.096$)

When device conditions were compared with other device conditions, participants rated the turn as being significantly easier in the visual and audible sensor conditions than in the panoramic mirror conditions:

- Visual sensor vs. Panoramic mirror ($\chi^2 = 2.778, p = 0.096$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 2.778, p = 0.096$)

When comparing the device conditions against the unrestricted condition, artificially restricted participants found it significantly easier to complete the turn in the unrestricted condition than in the reversing camera, audible sensor and panoramic mirror conditions:

- Unrestricted vs. Reversing camera ($\chi^2 = 4.500, p = 0.034$)
- Unrestricted vs. Audible sensor ($\chi^2 = 8.000, p = 0.005$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 10.000, p = 0.002$)

The comparison between unrestricted and visual sensor conditions approached significance; artificially restricted participants found it easier to complete the task in the unrestricted condition than in the visual sensor condition:

- Unrestricted vs. Visual sensor ($\chi^2 = 3.600, p = 0.058$)

### I.4.3.2 Validation participants

For the validation participants, when the device conditions were compared with the without device condition, there were two pairs which approached significance; participants rated the turn as being easier in the without device condition than it was in the visual sensor and panoramic mirror conditions:

- Without Device vs. Visual sensor ($\chi^2 = 3.000, p = 0.083$)
- Without Device vs. Panoramic mirror ($\chi^2 = 3.00, p = 0.083$)

When the device conditions were compared with each other for ease of turn, validation participants rated themselves as finding it significantly easier to make the turn reversing camera condition than in either the visual sensor and panoramic mirror conditions:

- Reversing camera vs. Visual sensor ($\chi^2 = 4.000, p = 0.046$)
- Reversing Camera vs. Panoramic mirror ($\chi^2 = 4.000, p = 0.046$)

### I.4.4 Confidence

This section describes the results of the comparisons of how confident or unconfident the artificially restricted participants rated themselves as feeling while completing the task between observation conditions. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Reversing camera vs. Restricted
3. Visual sensor vs. Restricted
4. Audible sensor vs. Restricted
5. Panoramic mirror vs. Restricted
6. Reversing camera vs. Visual sensor
7. Reversing camera vs. Audible sensor
8. Reversing camera vs. Panoramic mirror
9. Visual sensor vs. Audible sensor
10. Visual sensor vs. Panoramic mirror
11. Audible sensor vs. Panoramic mirror
12. Reversing camera vs. Unrestricted
13. Visual sensor vs. Unrestricted
14. Audible sensor vs. Unrestricted
15. Panoramic mirror vs. Unrestricted

Table 32 shows the mean and standard deviation of participants’ confidence ratings. For ease of interpretation, the columns for the reversing aids are colour-coded. The measure is coloured red if the participants’ confident ratings were lower than they were in the restricted condition. Measures are coloured blue if the difference was a rating which was the same as or lower than 0.5 different from the restricted rating. Figures shown in brackets demonstrate the magnitude and direction of the device conditions and the restricted condition.

### Table 32 Mean confidence ratings, artificially restricted participants

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean confidence ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Mean 9.4, S.D. 0.156</td>
</tr>
<tr>
<td>Restricted</td>
<td>Mean 7.5, S.D. 1.354</td>
</tr>
<tr>
<td>Reversing camera</td>
<td>Mean 7.5 (=), S.D. 1.716</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 6.9 (-0.6), S.D. 0.738</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 7.0 (-0.5), S.D. 2.000</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 6.2 (-1.3), S.D. 1.317</td>
</tr>
</tbody>
</table>

### 1.4.4.1 Artificially restricted participants

The artificially restricted participants rated themselves as being significantly more confident in the unrestricted condition than in the restricted condition:
- Unrestricted vs. Restricted ($\chi^2 =8.000$, p =0.005)

When all of the device conditions were compared with each other, the artificially restricted participants rated themselves as feeling significantly more confident in the reversing camera condition than in the panoramic mirror condition:
- Reversing camera vs. Panoramic mirror ($\chi^2 =5.000$, p =0.025)

When all of the device conditions were separately compared with the restricted condition, the artificially restricted participants rated themselves as being significantly more confident in the restricted condition than in the panoramic mirror condition:
- Restricted vs. Panoramic mirror ($\chi^2 =4.500$, p =0.034)

When all of the device conditions were compared with the unrestricted condition, the participants rated themselves as feeling significantly more confident performing the task in the unrestricted condition than in any other condition:
- Unrestricted vs. Reversing camera ($\chi^2 =6.400$, p =0.011)
Unrestricted vs. Visual sensor \((\chi^2 = 10.000, p = 0.002)\)
Unrestricted vs. Audible sensor \((\chi^2 = 8.000, p = 0.005)\)
Unrestricted vs. Panoramic mirror \((\chi^2 = 10.000, p = 0.002)\)

### I.4.4.2 Validation participants

The validation participants rated themselves as feeling most confident in the reversing camera condition and least confident in the panoramic mirror conditions.

The validation participants rated themselves as feeling significantly more confident in the without device condition than they did in the visual sensor condition:
- Without device vs. Visual sensor \((\chi^2 = 4.000, p = 0.046)\)

The comparison between the without device condition and the panoramic mirror condition approached significance; validation participants felt more confident without any devices than they did in the panoramic mirror condition:
- Without device vs. Panoramic mirror \((\chi^2 = 3.000, p = 0.083)\)

### I.4.5 Helpfulness of aid

This section describes the results of the comparisons of how helpful or unhelpful the artificially restricted participants rated the devices for helping them to complete the task. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Reversing camera vs. Visual sensor
2. Reversing camera vs. Audible sensor
3. Reversing camera vs. Panoramic mirror
4. Visual sensor vs. Audible sensor
5. Visual sensor vs. Panoramic mirror
6. Audible sensor vs. Panoramic mirror

Table 33 shows the mean and standard deviation of the artificially restricted participants’ ratings of device helpfulness. For ease of interpretation, the helpfulness column is colour coded. The least helpful device is coloured red and the most helpful device is coloured green.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean helpfulness ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversing camera</td>
<td>Mean 6.5</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.677</td>
</tr>
<tr>
<td>Visual sensor</td>
<td>Mean 4.8</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.201</td>
</tr>
<tr>
<td>Audible sensor</td>
<td>Mean 5.9</td>
</tr>
<tr>
<td></td>
<td>S.D. 3.247</td>
</tr>
<tr>
<td>Panoramic mirror</td>
<td>Mean 4.1</td>
</tr>
<tr>
<td></td>
<td>S.D. 2.424</td>
</tr>
</tbody>
</table>
I.4.5.1 Artificially restricted participants

Table 33 shows that the artificially restricted participants rated the reversing camera as the most helpful aid, and the panoramic mirror as the least helpful aid.

When device conditions were compared with each other for perceived helpfulness, no device was significantly more helpful than any other, however, the comparison between the reversing camera and visual sensor approached significance:

- Reversing camera vs. Visual sensor ($\chi^2 = 2.778, p = 0.096$)

I.4.5.2 Validation participants

When all of the devices were compared with each other, the validation participants rated the audible sensor as being significantly more helpful than the visual sensor and the panoramic mirror:

- Audible sensor vs. Visual sensor ($\chi^2 = 4.000, p = 0.046$)
- Audible sensor vs. Panoramic mirror ($\chi^2 = 4.000, p = 0.046$)

I.5 Blind spot scenario- 10mph, 30mph and combined

I.5.1 Quality of view

I.5.1.1 Artificially restricted participants

This section describes the results of the quality of view between the conditions for the 10 artificially restricted participants. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Blind Spot Mirror vs. Restricted
3. Panoramic Mirror vs. Restricted
4. Blind Spot Mirror vs. Panoramic Mirror
5. Blind Spot Mirror vs. Unrestricted
6. Panoramic Mirror vs. Unrestricted

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

Descriptive Statistics

Table 34 shows the mean and standard deviation of the artificially restricted participants’ quality of view ratings. For ease of interpretation, the columns for the panoramic mirror and blind spot mirror conditions are colour coded. The measure is coloured red if there was a worse quality of view rating compared with the restricted condition. The measures are coloured blue if the difference between the restricted condition and then device condition was the same or less than 0.5 rating points. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition. The descriptive statistics show that the subjective ratings of quality of view were highest in the unrestricted condition (at the 30 mph speed) and were lowest in the blind spot mirror condition (at the 10mph speed). The panoramic mirror appeared to provide the artificially restricted participants with the same or a better quality of view than they had in the restricted condition, while the blind spot mirror appeared to worsen the quality of view for the artificially restricted participants at both speeds.
Table 34 Mean quality of view ratings for each permutation, artificially restricted participants

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Unrestricted</th>
<th>Restricted</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mph</td>
<td>Mean</td>
<td>9.6</td>
<td>8.7</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.699</td>
<td>1.337</td>
<td>2.593</td>
</tr>
<tr>
<td>30mph</td>
<td>Mean</td>
<td>9.8</td>
<td>8.8</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.422</td>
<td>1.398</td>
<td>2.669</td>
</tr>
<tr>
<td>Both speeds</td>
<td>Mean</td>
<td>9.7</td>
<td>8.75</td>
<td>7.9</td>
</tr>
<tr>
<td>combined</td>
<td>S.D.</td>
<td>0.5605</td>
<td>1.3675</td>
<td>2.631</td>
</tr>
</tbody>
</table>

10mph Quality Ratings

At the 10mph speed, the mean quality of view ratings in the unrestricted condition was significantly higher than the restricted and blind spot mirror conditions:
- Unrestricted vs. Restricted ($\chi^2 = 5.000, p = 0.025$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 7.000, p = 0.008$)

There were no other significantly different pairs in this comparison.

30mph Quality Ratings

At the 30mph speed, the mean quality of view ratings in the unrestricted condition were significantly higher than any other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 4.000, p = 0.046$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 5.000, p = 0.025$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 4.000, p = 0.046$)

There were no other significantly different pairs in this comparison.

Combined results and summary

The quality ratings for all permutations of the blind spot task were combined by creating an average of all quality ratings within each condition these can be seen in Figure 77. The combined variables were then subjected to the same analysis as individual permutations.
The results show that the quality rating was significantly higher in the unrestricted condition compared to all other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 9.000$, $p = 0.003$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 12.000$, $p = 0.001$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 4.500$, $p = 0.034$)

There were no other significant differences in this comparison.

1.5.1.2 Validation participants

**10mph Quality Ratings**

At the 10mph speed, the mean quality of view ratings in the without device condition was higher than the blind spot mirror conditions, this difference approached significance:
- Without Device vs. Blind spot mirror ($\chi^2 = 3.000$, $p = 0.083$)

The comparison between the Blind spot mirror and the panoramic mirror also approached significance, with participants rating the blind spot mirror as providing a better quality of view than the panoramic mirror:
- Panoramic mirror vs. Blind spot mirror ($\chi^2 = 3.000$, $p = 0.083$)

There were no other significantly different pairs in this comparison.

**30mph Quality Ratings**

At the 30mph speed, the mean quality of view ratings in the without device condition were rated as being better than the quality of view provided by the blind spot mirror, this difference approached significance:
- Without Device vs. Blind spot mirror ($\chi^2 = 3.000$, $p = 0.083$)

There were no other significantly different pairs in this comparison.
I.5.2 Clarity of view

I.5.2.1 Artificially restricted participants

This section describes the results of the clarity of view between the conditions for the 10 artificially restricted participants. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Blind Spot Mirror vs. Restricted
3. Panoramic Mirror vs. Restricted
4. Blind Spot Mirror vs. Panoramic Mirror
5. Blind Spot Mirror vs. Unrestricted
6. Panoramic Mirror vs. Unrestricted

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

Table 35 shows the mean and standard deviation of the artificially restricted participants’ clarity of view ratings. For ease of interpretation, the columns for the panoramic mirror and blind spot mirror conditions are colour coded. The measure is green if there was an improvement (i.e. a better clarity of view rating) compared to the restricted condition and coloured red if there was a worse clarity of view rating compared with the restricted condition. The measures are coloured blue if the difference between the restricted condition and then device condition was the same or less than 0.5 rating points. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

The descriptive statistics show that the subjective ratings of clarity of view were highest in the unrestricted condition (at the 10 mph speed) and were lowest in the blind spot mirror condition (at the 10mph speed). The panoramic mirror appeared to provide the artificially restricted participants with the same or a better clarity of view than they had in the restricted condition, while the blind spot mirror appeared to worsen the quality of view for the artificially restricted participants at both speeds.

**Table 35 Mean Clarity of view ratings for each permutation, artificially restricted participants**

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Unrestricted</th>
<th>Restricted</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mph</td>
<td>Mean</td>
<td>9.7</td>
<td>8.7</td>
<td>8.0 (-0.7)</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.483</td>
<td>1.252</td>
<td>2.625</td>
</tr>
<tr>
<td>30mph</td>
<td>Mean</td>
<td>9.4</td>
<td>8.5</td>
<td>8.2 (-0.3)</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.966</td>
<td>1.716</td>
<td>2.658</td>
</tr>
<tr>
<td>Both speeds</td>
<td>Mean</td>
<td>9.55</td>
<td>8.6</td>
<td>8.1 (-0.5)</td>
</tr>
<tr>
<td>combined</td>
<td>S.D.</td>
<td>0.7245</td>
<td>1.484</td>
<td>2.6415</td>
</tr>
</tbody>
</table>

**10mph Clarity Ratings**

At the 10mph speed, the mean clarity of view ratings in the unrestricted condition were significantly higher than the restricted and blind spot mirror conditions:
• Unrestricted vs. Restricted ($\chi^2 = 5.000$, $p = 0.025$)
• Unrestricted vs. Blind spot mirror ($\chi^2 = 6.000$, $p = 0.014$)

There were no other significant pairs; however, other comparison approached significance:
• Panoramic mirror vs. Restricted ($\chi^2 = 3.571$, $p = 0.059$)
• Panoramic mirror vs. Blind spot mirror ($\chi^2 = 3.571$, $p = 0.059$)

30mph Clarity Ratings, artificially restricted participants

At the 30mph speed, there were no significant differences in the clarity between any of the pairs; however, the unrestricted vs. restricted pair approached significance:
• Unrestricted vs. Restricted ($\chi^2 = 3.000$, $p = 0.083$)

Combined results and summary, artificially restricted participants

The clarity ratings for all permutations of the blind spot task were combined by creating an average of all quality ratings within each condition, these can be seen in Figure 78. The combined variables were then subjected to the same analysis as individual permutations.

![Figure 78 Clarity rating for all permutations combined](image)

The combined results indicate that, the mean clarity of view ratings in the Unrestricted condition were significantly higher than the restricted and blind spot mirror conditions:
• Unrestricted vs. Restricted ($\chi^2 = 8.000$, $p = 0.005$)
• Unrestricted vs. Blind spot mirror ($\chi^2 = 7.364$, $p = 0.007$)

There were no other significantly different pairs in this comparison.
I.5.2.2 Validation participants

10mph Clarity Ratings

At the 10mph speed, the mean clarity of view ratings in the without device condition was higher than the blind spot mirror condition, this difference approached significance:
- Without Device vs. Blind spot mirror ($\chi^2 = 3.000, p = 0.083$)

For the validation participants, the clarity of view provided by the panoramic mirror was better than that of the blind spot mirror, this difference approached significance at the 10mph speed:
- Panoramic Mirror vs. Blind spot mirror ($\chi^2 = 3.000, p = 0.083$)

30mph Clarity Ratings

At the 30mph speed, there were no significant differences in the clarity between any of the pairs; however, the without device condition compared with the blind spot mirror approached significance, it was clarity of view ratings for the validation participants were higher in the without device condition than in the blind spot mirror condition:
- Without Device vs. Blind spot mirror ($\chi^2 = 3.000, p = 0.083$)

I.5.3 Judgement of speed

This section describes the results of the how easy or difficult the artificially restricted participants considered judging the speed of an approaching vehicle to be between the conditions for the 10 artificially restricted participants. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:
1. Restricted vs. Unrestricted
2. Blind Spot Mirror vs. Restricted
3. Panoramic Mirror vs. Restricted
4. Blind Spot Mirror vs. Panoramic Mirror
5. Blind Spot Mirror vs. Unrestricted
6. Panoramic Mirror vs. Unrestricted

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

I.5.3.1 Artificially restricted participants

Descriptive Statistics

Table 36 shows the mean and standard deviation of the artificially restricted participants’ ratings of how easy or difficult they found it to judge the speed of a vehicle approaching from behind. For ease of interpretation, the columns for the panoramic mirror and blind spot mirror conditions are colour coded. The measure is coloured red if there it was more difficult to judge the speed of the approaching vehicle compared with the restricted condition. The measures are coloured blue if the difference between the restricted condition and then device condition was the same or less than 0.5 rating points. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

The descriptive statistics show that the artificially restricted participants rated the ability to judge the speed of an approaching vehicle most highly in the unrestricted condition and
lowest in the blind spot mirror condition. The participants rated it as being significantly easier
to judge the speed of the approaching vehicle in the unrestricted condition than in any other condition. When the device conditions were compared with each other, the ability to
determine the speed of the approaching vehicle was easier in the panoramic mirror condition than it was in the blind spot mirror condition, although this difference was not statistically
significant. Neither of the blind spot devices adequately compensated to the level of an
unrestricted driver’s ability to judge the speed of an approaching vehicle.

### Table 36 Mean rating of ease of judgement of speed for each permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Unrestricted</th>
<th>Restricted</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10mph</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.10</td>
<td>7.8</td>
<td>6.9 (-0.9)</td>
<td>7.3 (-0.5)</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.101</td>
<td>1.814</td>
<td>2.601</td>
<td>1.947</td>
</tr>
<tr>
<td><strong>30mph</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.4</td>
<td>8.5</td>
<td>6.2 (-2.3)</td>
<td>8.8 (+0.3)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.699</td>
<td>1.716</td>
<td>2.821</td>
<td>1.398</td>
</tr>
<tr>
<td><strong>Both speeds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>combined</td>
<td>9.25</td>
<td>8.15</td>
<td>6.55 (-1.6)</td>
<td>8.05 (-0.1)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.9</td>
<td>1.765</td>
<td>2.711</td>
<td>1.6725</td>
</tr>
</tbody>
</table>

### 10mph Speed Judgements

At the 10mph speed, the speed of the approaching vehicle was judged as being significantly
easier to judge in the unrestricted condition than in the blind spot mirror and panoramic
mirror conditions:
- Unrestricted vs. Blind spot mirror ($\chi^2=5.000$, $p=0.025$)
- Unrestricted vs. Panoramic mirror ($\chi^2=7.000$, $p=0.008$)

There were no other significant pairs in this comparison.

### 30mph Speed Judgements

At the 30mph speed, the speed of the approaching vehicle was judged as being significantly
easier to judge in the unrestricted condition than in any other condition:
- Unrestricted vs. Restricted ($\chi^2=8.000$, $p=0.005$)
- Unrestricted vs. Blind spot mirror ($\chi^2=10.000$, $p=0.002$)
- Unrestricted vs. Panoramic mirror ($\chi^2=9.000$, $p=0.003$)

There were no other significant pairs in this comparison.

### Combined results and summary

The ease of judgement of speed ratings for all permutations of the blind spot task were
combined by creating an average of all quality ratings within each condition; these can be
seen in Figure 79. The combined variables were then subjected to the same analysis as
individual permutations.
Figure 79 Rating of ease of judgement of speed for all permutations combined

When the data from the two speeds were combined, the speed of the approaching vehicle was rated as being significantly easier to judge in the unrestricted condition than in any other condition:

- Unrestricted vs. Restricted ($\chi^2 = 10.286, p = 0.001$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 15.000, p = <0.001$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 16.000, p = <0.001$)

There were no other significant pairs in this comparison.

I.5.3.2 Validation participants

The ability of the validation participants to judge the speed of an approaching vehicle was rated highest in the panoramic mirror condition and lowest in the blind spot mirror condition for the validation participants. When the device conditions were compared with each other, the ability to judge the speed of the approaching vehicle was easier in the panoramic mirror condition than it was in the blind spot mirror condition. As the rating for ease of speed judgement was highest in the panoramic mirror condition, this suggests that the panoramic mirror compensates for restricted neck and trunk movement in the judgement of speed.

At 10mph, the validation participants rated it as being easier to judge the speed of the vehicle approaching from behind in the without device condition than it was in the blind spot mirror, this difference approached significance:

- Without device vs. Blind spot mirror ($\chi^2 = 3.000, p = 0.083$)

At 10mph, there were no other significantly different pairs in this comparison.
At the 30mph speed, again, the validation participants rated it as being easier to judge the speed of the vehicle approaching from behind in the without device condition than it was in the blind spot mirror, this difference approached significance:

- Without device vs. Blind spot mirror ($\chi^2 = 3.000$, $p = 0.083$)

At 30mph, there were no other significantly different pairs in this comparison.

### I.5.4 Judgement of position

This section describes the results of the how easy or difficult the artificially restricted participants considered judging the position of an approaching vehicle to be between the conditions for the 10 artificially restricted participants. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Blind Spot Mirror vs. Restricted
3. Panoramic Mirror vs. Restricted
4. Blind Spot Mirror vs. Panoramic Mirror
5. Blind Spot Mirror vs. Unrestricted
6. Panoramic Mirror vs. Unrestricted

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

#### Descriptive Statistics

Table 37 shows the mean and standard deviation of the artificially restricted participants’ ratings of how easy or difficult they found it to judge the position of a vehicle approaching from behind. For ease of interpretation, the columns for the panoramic mirror and blind spot mirror conditions are colour coded. The measure is coloured red if there it was more difficult to judge the position of the approaching vehicle compared with the restricted condition. The measures are coloured blue if the difference between the restricted condition and then device condition was the same or less than 0.5 rating points. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

#### I.5.4.1 Artificially restricted participants

The artificially restricted participants’ ability to judge the position of an approaching vehicle was rated as being most difficult in the blind spot mirror condition, and easiest in the unrestricted condition. The position of the approaching vehicle was rated as being significantly easier to judge in the unrestricted condition than in any other condition. There were no other significant pairs in the comparison.

When the device conditions were compared with each other, the ability to judge the position of the approaching vehicle was easier in the panoramic mirror condition than it was in the blind spot mirror condition, but this difference was not statistically significant. Neither of the devices adequately compensated to the level of an unrestricted driver’s ability to judge the position of an approaching vehicle.
<table>
<thead>
<tr>
<th>Permutation</th>
<th>Unrestricted</th>
<th>Restricted</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mph Mean</td>
<td>9.3</td>
<td>8.00</td>
<td>6.9 (-1.1)</td>
<td>8.10 (+0.1)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.949</td>
<td>1.633</td>
<td>2.470</td>
<td>1.853</td>
</tr>
<tr>
<td>30mph Mean</td>
<td>9.4</td>
<td>8.00</td>
<td>6.9 (-1.1)</td>
<td>7.7 (-0.3)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.699</td>
<td>1.491</td>
<td>2.514</td>
<td>2.003</td>
</tr>
<tr>
<td>Both speeds combined Mean</td>
<td>9.35</td>
<td>8</td>
<td>6.9 (-1.1)</td>
<td>7.9 (-0.1)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.824</td>
<td>1.562</td>
<td>2.492</td>
<td>1.928</td>
</tr>
</tbody>
</table>

**10mph Position Judgements**

At the 10mph speed, the position of the approaching vehicle was judged as being significantly easier to judge in the unrestricted condition than in any other condition:
- Unrestricted vs. Restricted ($\chi^2 =5.000, p =0.025$)
- Unrestricted vs. Blind spot mirror ($\chi^2 =5.444, p =0.020$)
- Unrestricted vs. Panoramic mirror ($\chi^2 =4.000, p =0.046$)

There were no other significant pairs in this comparison.

**30mph Position Judgements**

Like the 10mph speed, at the 30mph speed, the position of the approaching vehicle was judged as being significantly easier to judge in the unrestricted condition than in any other condition:
- Unrestricted vs. Restricted ($\chi^2 =8.000, p =0.005$)
- Unrestricted vs. Blind spot mirror ($\chi^2 =8.000, p =0.005$)
- Unrestricted vs. Panoramic mirror ($\chi^2 =8.000, p =0.005$)

**Combined results and summary**

The ease of judgement of position ratings for all permutations of the blind spot task were combined by creating an average of all quality ratings within each condition; these can be seen in Figure 80. The combined variables were then subjected to the same analysis as individual permutations.
When the data from the two speeds were combined, the position of the approaching vehicle was judged as being significantly easier to judge in the unrestricted condition than in any other condition:

- Unrestricted vs. Restricted ($\chi^2 = 13.000$, $p <= 0.001$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 13.235$, $p <= 0.001$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 12.000$, $p = 0.001$)

There were no other significant pairs in this comparison.

### Validation participants

The validation participants’ ability to judge the position of an approaching vehicle was rated as being most difficult in the blind spot mirror condition, and easiest in the panoramic mirror condition. When the device conditions were compared with each other, the ability to judge the position of the approaching vehicle was easier in the panoramic mirror condition than it was in the blind spot mirror condition.

At 10mph, the validation participants judged it as being easier in to judge the position of a vehicle approaching from behind in the Without device condition than in the blind spot mirror condition; they also rated it as being easier to judge the position of the vehicle in the panoramic mirror condition than in the blind spot mirror condition, both of these differences approached significance:

- Without device vs. Blind spot mirror ($\chi^2 = 3.000$, $p = 0.083$)
- Panoramic Mirror vs. Blind Spot Mirror ($\chi^2 = 3.000$, $p = 0.083$)
At 30mph, the validation participants judged it as being easier in to judge the position of a vehicle approaching from behind in the Without device condition than in the blind spot mirror condition; they also rated it as being easier to judge the position of the vehicle in the panoramic mirror condition than in the blind spot mirror condition, both of these differences approached significance:

- Without Device vs. Blind Spot Mirror \( \chi^2 = 3.000, p = 0.083 \)
- Panoramic Mirror vs. Blind Spot Mirror \( \chi^2 = 3.000, p = 0.083 \)

### 1.5.5 Confidence

This section describes the results of the how confident or unconfident the 10 artificially restricted participants rated themselves as feeling if they had to make a lane change between the conditions. All analyses in this section were conducted using a series of Friedman tests to examine the following pairs:

1. Restricted vs. Unrestricted
2. Blind Spot Mirror vs. Restricted
3. Panoramic Mirror vs. Restricted
4. Blind Spot Mirror vs. Panoramic Mirror
5. Blind Spot Mirror vs. Unrestricted
6. Panoramic Mirror vs. Unrestricted

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

**Descriptive Statistics**

Table 38 shows the mean and standard deviation of the artificially restricted participants’ ratings of how confident they would feel making a lane change. For ease of interpretation, the columns for the panoramic mirror and Blind Spot mirror conditions are colour coded. The measure coloured red if participant would feel less confident compared with the restricted condition. The measures are coloured blue if the difference between the restricted condition and then device condition was the same or less than 0.5 rating points. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition.

**12.1.1.2 Artificially restricted participants**

The artificially restricted participants’ confidence ratings were significantly higher in the unrestricted condition compared with all other conditions. There were no other significant differences, although the comparison between the blind spot mirror and panoramic mirror conditions approached significance. The artificially restricted participants rated themselves as feeling slightly more confident in the panoramic mirror condition than they did in the restricted condition but this difference was not statistically significant. Therefore it is thought that neither of the devices adequately compensate to the level of the unrestricted driver.
Table 38 Mean confidence rating for each permutation

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Unrestricted</th>
<th>Restricted</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mph Mean</td>
<td>9.6</td>
<td>7.4</td>
<td>6.1 (-1.3)</td>
<td>7.4 (=)</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.843</td>
<td>1.776</td>
<td>3.071</td>
<td>2.633</td>
</tr>
<tr>
<td>30mph Mean</td>
<td>8.9</td>
<td>6.8</td>
<td>5.7 (-1.1)</td>
<td>7.2 (+0.4)</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.370</td>
<td>2.658</td>
<td>3.302</td>
<td>3.120</td>
</tr>
<tr>
<td>Both speeds</td>
<td>9.25</td>
<td>7.1</td>
<td>5.9 (-1.2)</td>
<td>7.3 (+0.2)</td>
</tr>
<tr>
<td>combined Mean</td>
<td>1.1065</td>
<td>2.217</td>
<td>3.1865</td>
<td>2.8765</td>
</tr>
</tbody>
</table>

10mph Confidence ratings
At the 10mph speed, the mean confidence ratings in the unrestricted condition were significantly higher than any other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 7.000$, $p = 0.008$)
- Unrestricted vs. Blind Spot Mirror ($\chi^2 = 9.000$, $p = 0.003$)
- Unrestricted vs. Panoramic Mirror ($\chi^2 = 5.000$, $p = 0.025$)

30mph Confidence ratings
Similarly to the 10mph speed, at the 30mph speed, the mean quality of view ratings in the unrestricted condition were significantly higher than any other conditions:
- Unrestricted vs. Restricted ($\chi^2 = 8.000$, $p = 0.005$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 8.000$, $p = 0.005$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 5.000$, $p = 0.025$)

Combined results and summary
The confidence ratings for all permutations of the blind spot task were combined by creating an average of all quality ratings within each condition; these results can be seen in Figure 81. The combined variables were then subjected to the same analysis as individual permutations.
The combined results show that the confidence rating was significantly higher in the unrestricted condition compared with all other conditions:

- Unrestricted vs. Restricted ($\chi^2 = 9.000, p = 0.003$)
- Unrestricted vs. Blind spot mirror ($\chi^2 = 12.000, p = 0.001$)
- Unrestricted vs. Panoramic mirror ($\chi^2 = 4.500, p = 0.034$)

There were no other significant differences, although the comparison between the Blind spot mirror and panoramic mirror conditions approached significance:

- Blind Spot Mirror vs. Panoramic Mirror ($\chi^2 = 3.769, p = 0.52$)

### Validation Participants

Validation participants’ confidence ratings were highest in the panoramic mirror condition and were lowest in the blind spot mirror condition. The validation participants rated themselves as feeling more confident in the panoramic mirror condition than they did in their normal Without Device condition; and, although not significant, this suggests that the panoramic mirror may compensate for their impaired function to a degree.

At the 10mph speed, there were no significant differences between the Without Device condition and the device conditions. There was however, a difference between the blind spot mirror and the panoramic mirror; validation participants rated themselves as feeling more confident in the panoramic mirror condition than in the blind spot mirror condition, this difference approached significance:

- Panoramic mirror vs. blind spot mirror ($\chi^2 = 3.769, p = 0.52$)
At the 30mph speed and the combined speed, again, there were no significant differences between the without device condition and the device conditions. There was however, a difference between the blind spot mirror and the panoramic mirror; validation participants rated themselves as feeling more confident in the Panoramic Mirror condition than in the blind spot mirror condition, this difference approached significance:
- Panoramic mirror vs. blind spot mirror ($\chi^2 =3.769$, $p =0.52$)

### I.5.6 Helpfulness

This section describes the results of the how helpful or unhelpful the 10 artificially restricted participants rated the two devices. All analyses in this section were conducted using a series of Friedman tests to examine the following pair:
- Blind Spot Mirror vs. Panoramic Mirror

The two speeds (10mph and 30mph) were conducted separately, then an average rating was calculated across both speeds and analysed using the same method.

**Descriptive Statistics**

Table 39 shows the mean helpfulness rating for the artificially restricted participants. For ease of interpretation, the columns for the panoramic mirror and blind spot mirror conditions are colour coded. The measure is green if there was an improvement (i.e. the participant would feel more confident) compared to the restricted condition and coloured red if participant would feel less confident compared with the restricted condition. Figures shown in brackets below the means indicated the magnitude of the difference between the device conditions and the restricted condition. The table shows that at both speeds, the blind spot mirror was rated as being less helpful than the panoramic mirror.

<table>
<thead>
<tr>
<th>Permutation</th>
<th>Blind spot mirror</th>
<th>Panoramic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mph Mean</td>
<td>4.6</td>
<td>7</td>
</tr>
<tr>
<td>10mph S.D.</td>
<td>2.797</td>
<td>2.981</td>
</tr>
<tr>
<td>30mph Mean</td>
<td>4.7</td>
<td>6.7</td>
</tr>
<tr>
<td>30mph S.D.</td>
<td>2.946</td>
<td>3.268</td>
</tr>
<tr>
<td>Both speeds combined</td>
<td>Mean 4.65</td>
<td>6.85</td>
</tr>
<tr>
<td>Both speeds combined</td>
<td>S.D. 2.8715</td>
<td>3.1245</td>
</tr>
</tbody>
</table>

### I.5.6.1 Artificially restricted participants

**10mph Helpfulness ratings**

At the 10mph speed, the panoramic mirror was considered to be significantly more helpful than the blind spot mirror:
- Panoramic mirror vs. blind spot mirror ($\chi^2 =5.444$, $p =0.020$)

**30mph Helpfulness ratings**

When the approaching car was travelling at 30mph, there was no significant difference between the perceived helpfulness of the two devices, although the comparison was approaching significance:
- Panoramic Mirror vs. Blind Spot Mirror ($\chi^2 =2.778$, $p =0.096$) approaching significance
**Combined results and summary**

The helpfulness ratings for both appropriate permutations of the blind spot task were combined by creating an average of all helpfulness ratings within each device condition; these can be seen in Figure 82. The combined variables were then subjected to the same analysis as individual permutations.

![Combined results and summary](image)

**Figure 82 Mean helpfulness rating for all permutations combined**

The combined comparison between the panoramic mirror and blind spot mirror conditions showed that the panoramic mirror was perceived as being significantly more helpful than the blind spot mirror in this task:

- Panoramic Mirror vs. Blind spot mirror \( (\chi^2 = 8.000, p = 0.005) \)

When the two blind spot devices were compared with each other and rated for their helpfulness, both groups of participants rated the Panoramic Mirror as being significantly more helpful than the Blind Spot Mirror for this task.

**I.5.6.2 Validation participants**

For the validation participants, when the blind spot mirror was compared with the panoramic mirror for helpfulness of aid, the difference approached significance at both speeds; the panoramic mirror was rated as being more helpful than the blind spot mirror:

Panoramic mirror vs. blind spot mirror \( (\chi^2 = 3.000, p = 0.083) \)
Abstract

The Transport Research Laboratory (TRL Ltd) was commissioned by the Department for Transport’s (DfT) Accessibility and Equalities Unit (AEU) to explore the issues surrounding use of observation devices by people with restricted neck, head or trunk movement. This group of people may find it difficult or painful to make observations during certain driving tasks, such as reversing or negotiating a junction, and may find it difficult to see into blind spots around the vehicle. This project consisted of a consultation of key stakeholders, review of available technologies, user survey, in-depth evaluation of selected devices, and user testing. This report details the full technical findings of the project with additional data and recommendations made regarding the use of the devices assessed, provision of information to users, training of users, design of the devices, and licensing policy.
Technical Report: Observation technologies for drivers with restricted head or trunk movement

by T Luke, C Inwood, and R Hutchins

Published Project Report PPR208