CHAPTER 2

Study Design
Because Chapter 3, 4 and 5 have been based on published journal articles, some overlap might occur between these chapters and the present one. The goal of this chapter is to give a more in-depth understanding of how this study was designed and how the different parts of the study have been developed.

Participants

Both normal-sighted and visually impaired individuals took part in the project. Participants were recruited using digital and paper newsletters within Royal Dutch Visio, Bartiméus, patient organisations and local newspapers. To those who showed interest in participating in the study, a letter was sent including a short questionnaire, a letter of consent, and for visually impaired people a consent form to obtain their medical data from their ophthalmologist or rehabilitation centre. The questionnaire included questions about personal details (e.g., age), visual functioning, and physical and mental health, and was used to make a pre-selection of potential participants. Possible participants had to be between 50 and 75 years of age, and be free from neurological disorders (e.g., dementia, acquired brain injury, oculomotor dysfunction), psychiatric disorders, motor impairment that would hinder the operation of a mobility scooter (e.g., tremor), severe hearing problems, or alcohol or drug addiction. Visual inclusion criteria were based on the Dutch visual standards for car driving (Table 2.1). In line with the European visual standards for driving, minimum visual acuity and visual field for car drivers in the Netherlands are 0.5 (decimal Snellen notation) and 120° respectively. In exceptional cases people with either visual acuity between 0.4 and 0.5 or horizontal visual field between 90 and 120° can get a regular driving licence after a positive practical fitness-to-drive test by the Dutch driving licence authority (Centraal Bureau Rijvaardigheidsbewijzen, CBR). In addition to that, people with a visual acuity between 0.16 and 0.5 can be allowed to drive cars with a bioptic telescope system (BTS). Therefore, we created two groups of participants with low visual acuity: those that were legally allowed to drive a car under certain circumstances (low visual acuity) and those that were not legally permitted to drive cars (very low visual acuity). Only those people whose visual impairment matched those criteria were invited to take part in the experiment.
### Table 2.1. Classification of participant groups based on visual abilities

<table>
<thead>
<tr>
<th>Group</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low visual acuity</td>
<td>Binocular visual acuity: 0.01–0.15 (Snellen 6/600–6/40 or 20/2000–20/133; LogMAR 2–0.82; intact peripheral field (peripheral VFS &gt; 30/40)</td>
</tr>
<tr>
<td>Low visual acuity</td>
<td>Binocular visual acuity: 0.16–0.4 (Decimal Snellen; 6/38–6/15 or 20/125–20/50; LogMAR 0.8–0.4; intact peripheral field (peripheral VFSb &gt; 30/40)</td>
</tr>
<tr>
<td>Peripheral visual field defect</td>
<td>Binocular visual acuity ≥ 0.5 (Snellen ≥ 6/12 or 20/40; LogMAR ≤ 0.3); peripheral visual field impairment outside central 20° (peripheral VFS ≤ 30/40)</td>
</tr>
<tr>
<td>Combination</td>
<td>Combination of low visual acuity and visual field defect; binocular visual acuity ≤ 0.5 (Snellen ≤ 6/12 or 20/40; LogMAR ≥ 0.3) and non-specified peripheral visual field defect or central visual field defect inside 20° (central VFS ≤ 50/60)</td>
</tr>
<tr>
<td>Controls</td>
<td>Binocular visual acuity ≥ 0.8 (Snellen ≥6/8 or 20/25; LogMAR ≤ 0.1); no peripheral or central visual field defects</td>
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*a* own prescription  
*b* Visual Field Score (Colenbrander, 2001); explanation see in text

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### Table 2.2. Visual information per group. Binocular visual acuity is displayed in its decimal Snellen notation. The Visual Field Score is calculated using the III-4e isopter of the Goldmann perimeter.

<table>
<thead>
<tr>
<th></th>
<th>Very low visual acuity</th>
<th>Low visual acuity</th>
<th>Peripheral visual field defect</th>
<th>Combined group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median ± IQR</strong>a</td>
<td>0.08 ± 0.05</td>
<td>0.22 ± 0.10</td>
<td>0.94 ± 0.41</td>
<td>0.25 ± 0.28</td>
<td>1.14 ± 0.37</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>0.03 - 0.15</td>
<td>0.17 - 0.40</td>
<td>0.57 - 1.22</td>
<td>0.03 - 0.74</td>
<td>0.84 - 1.68</td>
</tr>
</tbody>
</table>

**VFSb (mean ± SD)**

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Peripheral</th>
<th>Central</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td><strong>n/a</strong>c</td>
<td>44 ± 22</td>
<td>67 ± 20</td>
<td>97 ± 1</td>
</tr>
<tr>
<td><strong>Peripheral</strong></td>
<td>6 ± 7</td>
<td>18 ± 9</td>
<td>38 ± 10</td>
</tr>
<tr>
<td><strong>Central</strong></td>
<td>38 ± 18</td>
<td>48 ± 20</td>
<td>60 ± 0</td>
</tr>
</tbody>
</table>

*a* IQR = Interquartile Range  
*b* VFS = Visual Field Score (Colenbrander, 2001, explanation see in p. 18)  
*c* Due to our assessment method for visual field size (Goldman perimeter) the VFS could not be reliably measured for these groups
Based on the first selection, 105 participants took part in the experiment. Visual functions (visual acuity and visual field; see further below) were assessed as part of the experiment to establish correct visual data on the day of the assessment. Based on this assessment, 7 participants had to be excluded from analysis since these participants did not fit in any of the categories described in Table 2.1. The exact number of participants per group is dependent on the different parts of the experiment and is reported in the relevant chapters. A summary of the average visual ability per group is given in Table 2.2.

Procedure

The experiment took place at the University Medical Center Groningen (UMCG), the Netherlands, and took approximately 6 hours per participant to complete. Participants started with a neuropsychological test battery, followed by visual functioning assessment, a mobility scooter training session and on-road drive in a mobility scooter, and a number of drives in a microcar- and mobility scooter driving simulator. Sufficient breaks were implemented and lunch was offered to prevent fatigue and a decline in attention.

Visual functioning

On the day of the experiment, visual functioning was assessed binocularly with the participants’ own prescription at 500 lux. Visual acuity was measured using the Early Treatment Diabetic Retinopathy Study (ETDRS) 2000 letter chart at 4 metres (Ferris, Kassoff, Bresnick, & Bailey, 1982). Peripheral visual field was determined with the III-4e-isopter of the Goldman perimeter.

An independent orthoptist converted the measured visual field into a visual field score (VFS). The VFS is a measurement determining the impact of visual field impairment on mobility (Colenbrander, 2001, Rondinelli, 2007). The score can be calculated by counting points according to a standardised overlay grid (Langelaan, Wouters, Moll, Boer, & Rens, 2005), using the III-4e isopter of the Goldmann perimeter. In total, 100 points can be achieved covering a field with a mean radius of 60°. Fifty percent more weight is given to the lower quadrants, since this part is more important for mobility (Rondinelli, 2007). In this experiment, a maximum of 60 points are given to the central visual field (20°); the peripheral visual field has a maximum of 40 points. Inclusion criteria were a score of less than 50 points for the central visual field (out of 60 possible points), and less than 30 points (out of
40 possible points) for the peripheral visual field.

Neuropsychological assessment

A neuropsychological test battery was composed that met a number of criteria: (1) Tests were previously used in research on driving performance, (2) tests had to be feasible for people with visual impairment, (3) the maximum total duration of the tests had to be approximately 20 minutes to keep the workload to a minimum, (4) tests had possibly good validity and were internationally recognised. The choice of the neuropsychological tests was based on the knowledge of five independent experts involved in fitness-to-drive regulations in the Netherlands and Belgium and specialised in visual rehabilitation and neuropsychology. The decision process consisted of three steps: (1) collecting suitable tests (via email), (2), ranking of proposed tests followed by discussion (face-to-face meeting 1st round), (3) second ranking followed by discussion (face-to-face meeting 2nd round). After the second round of ranking, seven tests were chosen to be part of the neuropsychological test battery: Mini Mental Status Examination (MMSE), Trail Making Test (TMT), Rey Osterrieth Complex Figure, Schuhfried Reaction Times (Vienna Test System), Schuhfried Determination Test (Vienna Test System), Dot Counting Task, and Vlakveld Hazard Perception Task. To increase luminance contrast for the visually impaired participants and to improve scoring accuracy, a tablet version was created for the TMT and the Rey Osterrieth Complex Figure (software by Metrisquare B.V., Sittard, the Netherlands). Apart from the fact that participants drew on a 21-inch tablet instead of on paper, the tests did not differ from their original version. Before starting with the tests themselves, participants were given the opportunity to draw and write on the blank tablet screen to get accustomed to the tablet. The tablet was connected to a laptop which was used to start and stop the tests and on which the tests and the participants’ performance was displayed in real time. The individual tests are described in more detail in Chapter 7.

Mobility scooter

For the purpose of this study, a mobility scooter with 3 wheels and a maximum speed of 15km/h was used (Excel Excite 3 Galaxy). This model is commonly used in the Netherlands. It is an open vehicle that is 65cm wide and 141cm long. A mirror was fitted on each side of the tiller. Accelerating and decelerating are both regulated by the same finger-controlled throttle (Figure 2.1), which is frequently
used in mobility scooters. The throttle works on a see-saw principle: pulling the right throttle has the same effect as pushing the left throttle and vice versa. Pulling/pushing the throttle harder will increase the speed of the mobility scooter. To drive forwards, the right throttle is pulled (or left is pushed), to drive backwards, the left throttle is pulled (or right is pushed). The mobility scooter has an electro-mechanical dynamic, regenerative braking system (pulling/pushing the throttle disables the brakes). When the throttle is released, the mobility scooter slows down and stops. Braking is therefore not necessarily an active process as people are used to on bicycles, for example. Although a rear disk brake is fitted with a lever on the tiller, it is not commonly used. Furthermore, maximum speed can be limited by pressing the “turtle-button” (for low maximum speeds up to 6 km/h suitable for driving on the sidewalk) and/or turning a knob on the dashboard (Figure 2.1).

Our mobility scooter was modified by the official supplier for the purpose of this study (Schreuder Revalidatietechnieken, Groningen, the Netherlands). First, a supplementary emergency stop, operated with a remote control, allowed the test leader to stop the mobility scooter directly at all times from a distance. Second, to allow use of the mobility scooter as a mock-up in the driving simulator, the mobility scooter was equipped with the necessary interfacing to connect the mobility scooter to the PC’s running the driving simulator software. More information on

![Figure 2.1. Mobility Scooter dashboard](image)
the mobility scooter is described in Chapter 3, Chapter 4, and Chapter 5.

Driving simulator

The driving simulator consisted of a microcar or mobility scooter mock-up that stood in front of three big screens (ST Software Simulator Systems, Groningen, the Netherlands; Figure 2.2). The screens were arranged in a U-shape around the mock-ups, enabling a 180° view of the traffic environment. The microcar driving simulator projections further included a rear mirror. A fixed-base mock-up was used to assess driving performance in microcars. The mock-up consisted of a standard open car cabin, including an adjustable seat, steering wheel, indicators, pedals (accelerator and brake), a hand brake, and an automatic gear system. The maximum speed was 45km/h (the legal speed limit of microcars). The distance from the steering wheel of the mock-up to the middle screen was 110cm. The same mobility scooter that was used for the driving ability and on-road driving test as describes above was used for the driving simulator as well. The advantage of using the same mobility scooter was that participants were already accustomed to the mobility scooter, thereby improving the validity of the driving simulator tasks. The mobility scooter was positioned in front of the middle screen at a distance of 80cm from the front of the mobility scooter. Maximum simulated speed was 15km/h (the physical speed limit of the mobility scooter). The cabins were connected to three PC’s running the software for the driving simulation. The simulation software calculated all vehicle movements in the simulated world and the counterforces that acted on the steering in the vehicle model. The speed of acceleration and braking of the driving model in the simulator was kept the same as in the real world driving assessments.
The screen projectors operated at a frequency of 60Hz. The middle screen had a resolution of 1920x1080, the side screens had a resolution of 1024x768. The dimensions of the projections were 200x110cm. The software generated motor sounds of the microcar and mobility scooter and of the surrounding traffic, which was reproduced by two speakers positioned in front of the middle screen.

**Environments**

The virtual environments were especially designed for the purpose of this experiment. Three environments were developed for the microcar and mobility scooter simulator using ST simulation software (ST Software Simulator Systems, Groningen, the Netherlands). In the microcar driving simulator, participants drove only on the road, whereas for the mobility driving simulator, both a road and a pavement condition existed. For both vehicles, virtual environments with and without static obstacles and autonomously moving traffic agents were created. Obstacles and traffic agents were designed with different characteristics to explore if certain types of obstacles posed more difficulties for visually impaired people than others. These four different characteristics were: (1) small and low contrast (e.g., grey bollard), (2) small and high contrast (e.g., coloured bollard), (3) big and low contrast (e.g., grey parked car), and (4) big and high contrast (e.g., coloured bin). In addition, obstacles were either placed to the left or the right of the driving lane. Moving traffic agents were calculated by the software and controlled by a script that regulated all intended traffic interactions and conflicts during the simulator drive (e.g., cars, trucks, bicycles, pedestrians). They were divided into three categories: (1) coming from the left at an intersection, (2) coming from the right at an intersection, or (3) had to be overtaken (slow traffic agents travelling in the same direction and traffic agents approaching from the opposite direction). The different types of traffic agents were thus particularly aimed at people with visual field defects. Examples of the different types of obstacles can be viewed in Figure 2.3. A more detailed description of the different environments is given in Chapter 5.

**Determination of parameters**

The following parameters were measured during the driving simulator drives: driving speed, lateral position (lateral position is calculated as the mean lateral position relative to the driving lane centre), standard deviation lateral position (SDLP), distance between the microcar/mobility scooter and objects or traffic
agents, collisions with either objects or traffic agents, and time-to-collisions (TTC; the time at which a collision with another object (moving or static) will occur given the current speed and direction of the driver). In order to measure these parameters in the environments, a system was developed by ST Software to register these parameters. More specifically, static objects and moving traffic agents were geometrically defined in such a way that distances could be calculated (Figure 2.4).

To calculate the exact distance between the moving vehicle and an object/traffic agent at any given time, the vehicle was defined geometrically as well. This was achieved by adding a number of detection layers to the vehicle which extended up to 5m outside the vehicle. The distance of each of the different layers was set at 0.10m. As the vehicle approached an object, the object came into contact with the layers, enabling the calculation of the distance between moving vehicle and object. More specifically, the layer closest to the moving vehicle that came in contact with an object was used to give the minimum distance from the vehicle to the object (see Figure 2.5 for a simplified illustration of distance detection).

The TTC was continuously calculated based on speed and direction of the moving
vehicle for all objects and traffic agents in the driving environment. To take both speed and direction into account when measuring the TTC, the moving vehicle itself and other dynamic traffic participants were equipped with a virtual tube that consisted of a number of segments. The total length of the tube was 4 seconds, and its lengths and direction depended on the speed of the moving vehicles and the steering direction respectively. The higher the speed, the longer the tube. The origin of this tube corresponded with the front part of the moving vehicle and was thus able to predict where the moving vehicle would be in 4 seconds provided that speed and direction stayed the same. The estimation of the TTC started as soon as the tube intersected an object along its path (see Figure 2.6 for a simplified illustration of the virtual tube). Other dynamic traffic agents
Slow motorised traffic and vision

were also equipped with a virtual expanding tube. Whenever the moving vehicle encountered a dynamic traffic agent, the TTC would be estimated as soon as the tube of the moving vehicle and the tube of the other traffic agents crossed (Figure 2.7 for a simplified illustration). A TTC of zero indicated a collision.

Figure 2.6. Determining the TTC with a static object using a virtual tube

a) Collision predicted (TTC < 4)

b) No collision predicted due to direction (TTC > 4s)
c) No collision predicted due to low speed (TTC > 4s). The relatively lower speed in this situation compared to a and b can be seen on the basis of the shorter length of the tube and the shorter distances between the different discs.
b) No collision predicted (TTC > 4): The microcar has a higher speed than the traffic agent and will have left the crossing before a collision can take place if both vehicles continue with the same speed and direction.