US Department
of Transportation

**National Highway
Traffic Safety
Administration**

DOT HS 809 149 September 2000

Final Report

Non-planar driver's side rearview mirrors:

A Survey of Mirror types and European Driver Experience and a Driver Behavior Study on the Influence of Experience and Driver Age on Gap Acceptance and Vehicle Detection

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipients's Catalog No.
4. Title and Subtitle Non-planar driver's side rearview mirrors: A Survey of Mirror types and European Driver Experience and a Driver Behavior Study on the Influence of Experience and Driver Age on Gap Acceptance and Vehicle Detection		5. Report Date September 2000 6. Performing Organization Code
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12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, DC 20590		13. Type of Report and Period Covered Final Report Sept. 1997 – Jan. 2000 14. Sponsoring Agency Code
15. Supplementary Notes NHTSA Contract Monitor: Michael Perel, Office of Vehicle Safety Research		

16. Abstract

Some European drivers have been using different types of convex, driver-side rear-view mirrors which provide a wider field-of-view than flat mirrors, but produce a minified image. With a minified image, some drivers may have difficulty judging distances and approach speeds. To assess the potential benefits and difficulties experienced by European drivers using non-planar driver-side rearview mirrors, this research included a survey of mirror use as well as an experiment to measure the performance of drivers when making lane change decisions based on mirror information. In addition, an inventory of mirror characteristics on vehicles in use was performed. The survey found that only one third of the drivers knew what optical type of mirror they had. The field experiment quantified the tradeoff between drivers' improved detection of adjacent vehicles due to wider fields of view and their decision to make lane changes at smaller gaps to approaching vehicles. Drivers' experience with non-planar mirrors did not generally compensate for the negative effect of accepting smaller gaps, with the exception of drivers who were accustomed to spherical convex mirrors. There was no increase in the visual workload required to process information in non-planar mirrors. The conclusion was that the relative benefits of non-planar mirrors should be greater than the negative effects.

17. Key Words Mirrors, Driver behavior, Field of View, Driver Age,		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages	22. Price

Form DOT F1700.7 (8-72) **Reproduction of completed page authorized**

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LIST OF ABBREVIATIONS AND SYMBOLS

FOV	Field of view
NHTSA	National Highway Traffic Safety Administration
ROC	Radius of curvature
Std dev	Standard deviation
US DOT	United States Department of Transportation

1 INTRODUCTION

In the US, only planar driver's side rearview mirrors are allowed. At the passenger's side, spherical convex mirrors are also allowed. In Europe, non-planar rearview mirrors are allowed on both the passenger and the driver's side of the car. The use of conventional planar mirrors on the driver's side having a relatively large 'blind spot' may be related to 'lane change crashes', crashes occurring when a driver tries to change lanes and strikes or is struck by a vehicle in the adjacent lane. Non-planar mirrors provide a larger field of view than planar mirrors (in case of identical mirror dimensions), which may increase the chance of detecting the presence of vehicles in the area besides and behind the driver which otherwise would be in the 'blind spot' of a planar mirror.

However, there are also possible disadvantages of having non-planar mirrors on the driver's side. Non-planar mirrors will cause a slight distortion of the image (Walraven, 1974) and will lead to a reduction of the size of the image. From a traffic safety point of view this latter aspect might be important. A smaller image will be associated with a larger distance and thus an overestimation of the distance to a vehicle approaching from the rear may occur. Also the speed (i.e., closure rate) of an approaching car may be misjudged (or not perceived at all).

A key question is whether drivers who use non-planar mirrors on the driver's side are able to compensate for the possible underestimation introduced by the mirror. If drivers who are experienced with non-planar mirrors are able to estimate the distance and speed of a car closing in from the rear and the critical gap required to initiate a lane change as adequately as drivers using planar mirrors, then it may be advantageous to use non-planar mirrors on the driver's side. If, on the other hand, even after extended practice (e.g., using such a mirror for more than a year), the use of non-planar mirrors still results in an overestimation of the distance of the oncoming car with the consequence of accepting more critical gaps (shorter gaps) to initiate a lane change, then the value of these designs may need to be reassessed. In that case, other measures may be necessary to reduce the 'blind spot' accidents (e.g., lane change warning devices, better training to use the mirrors, etc.).

The current project was designed to determine whether drivers with long term experience with non-planar mirrors are able to adequately estimate critical gaps. Since this study was conducted in the Netherlands where non-planar mirrors are allowed, it was possible to recruit subjects having extensive experience with non-planar mirrors. The question addressed is whether drivers using non-planar mirrors would initiate a critical lane change later in time (at shorter distances from the oncoming car) than drivers using planar mirrors. Related to this question is whether the type of mirror would affect the effort required to make an adequate gap estimation. Even if drivers are capable of having an adequate gap estimation using non-planar mirrors, the question arises whether it would require more processing effort in terms of longer glance durations at the mirror, before an adequate decision can be made. From the traffic safety point of view, this would be disadvantageous, because it would imply that drivers using non-planar mirrors have their eyes longer off the road than those using planar mirrors. This may for example result in a higher incidence of rear end collisions. Because elderly drivers may have particular problems using non-planar mirrors (e.g., reduced visual accommodation abilities, smaller field of view, less flexible in changing strategies, more conservative judgements), the study included elderly drivers. Note however if elderly drivers are capable of using the non-planar mirrors adequately, they may benefit more from non-planar mirrors because they tend to have problems in turning their head for checking of the 'blind spot' when using planar mirrors.

Although it seems rather trivial that the increased field of view of non-planar mirrors will improve the detection of vehicles at close range, the image characteristics of non-planar mirrors may force drivers to invest more effort in the interpretation of the image, resulting in longer dwell times and reaction times.

Moreover, in case of non-planar mirrors it might be more difficult to assess whether or not one is just ahead of a vehicle in the other lane.

The National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation has asked the TNO Human Factors Research Institute to conduct a study investigating the effects of mirror type on driver behavior.

The total study comprised two phases. Phase 1 consisted of an inventory of mirror characteristics and a survey of drivers to find out what type of problems drivers encounter with these mirrors. In Phase 1A an inventory of the types of non-planar mirrors was made (Chapter 2, also separately reported by de Vos (in preparation a)). In Phase 1B a two stage approach was chosen: First in Phase 1B1, a limited number of drivers completed an elaborate questionnaire (Chapter 3, also published by de Vos, Theeuwes & Perel (1999)). Secondly, a shorter questionnaire was used to gather information from a larger sample of drivers (Phase 1B2) (Chapter 4, also separately reported by de Vos (in preparation b)).

Phase 2 was a field experiment in which it was investigated whether the type of mirror has effects on gap acceptance, on the detection of vehicles at close range besides and behind the driver and on visual sampling behavior. In this study, the effects of experience a driver has with a given type of mirror were analyzed as well as the effects of driver's age (Chapter 5). Finally, Chapters 6 gives the general discussion, conclusions and recommendations.

2 SURVEY OF MIRROR CHARACTERISTICS (Phase 1A)

In Phase 1A an inventory was made of what types of non-planar mirrors are currently in use. Three approaches were used to gather information. European regulations on rearview mirrors were scanned and information was gathered from car industry and mirror manufacturers (Section 2.1). Furthermore, mirror characteristics were registered for a representative sample of cars currently driving on the Dutch roads (Section 2.2) and, finally, the mirror characteristics and fields of view were measured for 9 recent cars (Section 2.3). The conclusions of the survey and the recommendations for the experimental part of the study are given in Section 2.4.

2.1 European regulations

Type-approval of road vehicles in Europe is governed by EC-directives and ECE-regulations. Regarding rearview mirrors the relevant directives are ECE-Regulation 46 (ECE, 1981) and EC-directive 71/127 (same requirements as ECE-regulation). These regulations on the one hand set criteria for rearview mirrors as such (e.g. criteria concerning impact resistance, the edges of the protective housing, dimensions of the reflecting surface, etc.) and on the other hand the regulations set the criteria for rearview mirrors installed on a vehicle (e.g. minimum required field of view). In the context of the present study the most relevant parts of these regulations are the parts on dimensions of the reflective surface, mirror radius of curvature and the part on required field of view. Underneath the relevant parts relating to passenger cars and small vans are summarized.

Dimensions reflecting surface

The dimensions of the reflecting surface of the interior rearview mirror should be such that it is possible to inscribe thereon a rectangle having one side of length 4 cm and the other a length "$a_{interior}$":

$$a_{interior} = 15 / (1 + 1000 / r_{interior}) \text{ cm} \quad (1)$$

in which $r_{interior}$ is the average radius of curvature over the interior mirror reflecting surface in millimeters. In case of a planar mirror surface, $a_{interior}$ is 15 cm, while the lower boundary for $a_{interior}$ is found for a convex mirror with the minimum radius of curvature for interior mirrors (1200 mm): $a_{interior, min}$ = 8.2 cm.

The dimensions of the reflecting surface for exterior rearview mirrors should be such that it is possible to inscribe thereon a rectangle of a height of 4 cm and of base length, in centimeters "$a_{exterior}$":

$$a_{exterior} = 13 / (1 + 1000 / r_{exterior}) \text{ cm} \quad (2)$$

in which $r_{exterior}$ is the average radius of curvature over the exterior mirror reflective surface in millimeters. In case of a planar mirror surface, $a_{exterior}$ is 13 cm, while the lower boundary for $a_{exterior}$ is found for a convex mirror with the minimum radius of curvature for exterior mirrors (1200 mm): $a_{exterior, min}$ = 7.1 cm.

Furthermore, the regulations stipulate that it should be possible to inscribe a segment 'b' in the exterior mirrors, parallel to the height of the rectangle and 7 cm of length.

Radius of curvature

The reflecting surface of a rearview mirror should be either planar or spherical convex. In case of rearview mirrors consisting of several reflecting surfaces which are either of different curvature or make an angle with each other, at least one of the reflecting surfaces should provide the field of view and have the dimensions specified for the class of mirror to which they belong. This means that due to the type-approval regulations, aspherical mirrors in Europe have a spherical main part which conforms to the regulations and the aspherical part is an addition, not subjected to any specific regulation, other than the general regulations such as that the total dimensions of any exterior mirror housing are not allowed to project more than 0.20 m beyond the overall width of the vehicle when not fitted with the rearview mirror. In order to identify the aspherical part as an additional mirror, there was an agreement between the type-approval bodies and industry that the border between spherical part and aspherical part should be marked. In addition to the existing ECE-regulations, regulations for aspherical mirrors are in preparation. Elements of these new regulations will be a description of the field of view with an aspherical mirror and a description of the aspherical geometry. Furthermore, it is proposed to allow the mirrors to project up to 0.25 m beyond the side of the car instead of 0.20 m.

ECE-regulation 46 prescribes that the radius of curvature is measured at three points situated at positions at 1/3, 1/2 and 2/3 of the distance along the arc of the reflecting surface passing through the center of the mirror and parallel to segment b or an arc perpendicular to it if this arc is the longest. At each of these points the radius of curvature is measured in two perpendicular directions. Radius of curvature r_{pi} at a point i is the average of the two perpendicular radii at that point. The radius of curvature r is the average of r_{p1}, r_{p2} and r_{p3}. The radius of curvature is measured with a spherometer, consisting of a rig with two fixed feeler points at a distance of 63 mm apart and a mobile point of a measuring clock in the middle. The radius of curvature can be calculated from the depression of the mobile point when the spherometer is pressed against the reflecting surface.

The differences between the radii of curvature measured at each point of the reflecting surface in two perpendicular directions should not exceed 0.15 r. The difference between any radii of curvature at different points of the reflecting surface should not exceed 0.15 r. When r is not less than 3000 mm, the value of 0.15 r is replaced by 0.25 r.

The radius of curvature should not be less than 1200 mm for interior rearview mirrors and main exterior mirrors for passenger cars and small vans. For trucks and buses the radius of curvature for main exterior mirrors should not be less than 1800 mm. The radius of curvature of 'wide angle' exterior mirrors and of 'close proximity' mirrors on trucks and buses should not be less than 400 mm.

Field of view

The specification of the required field of view is based on ambinocular vision, i.e. the total field of view obtained by the superimposition of the monocular fields of view of the right eye and the left eye.

For the interior rearview mirror, the field of view should be such that the driver can see at least a 20 m wide planar horizontal portion of the road centered on the vertical longitudinal median plane of the vehicle, from 60 m behind the driver's ocular points to the horizon. Head-rests, sunvisors, etc. may not obscure more than 15% of the prescribed field of view for the interior mirror.

The field of view for the driver's side exterior mirror should be such that the driver can see at least a 2.5 m wide portion of the road, which is bounded by the side of the vehicle and extends from 10 m behind the driver's ocular points to the horizon.

For vehicles having a maximum weight not exceeding 2000 kg, the field of view for the passenger's side mirror should be such that the driver can see at least a 4 m wide portion of the road extending from 20 m behind the driver's ocular points to the horizon. For all other vehicles the field of view should be such that the driver can see at least a 3.5 m wide portion of the road which extends from 30 m behind the driver's ocular points to the horizon and in addition the road should be visible over a width of 0.75 m from a point 4 m behind the ocular point of the driver.

The required fields of view for interior mirrors and main exterior mirrors are illustrated in Figure 1. Requirements for wide angle mirrors and close proximity mirrors for trucks and buses are not discussed in this report.

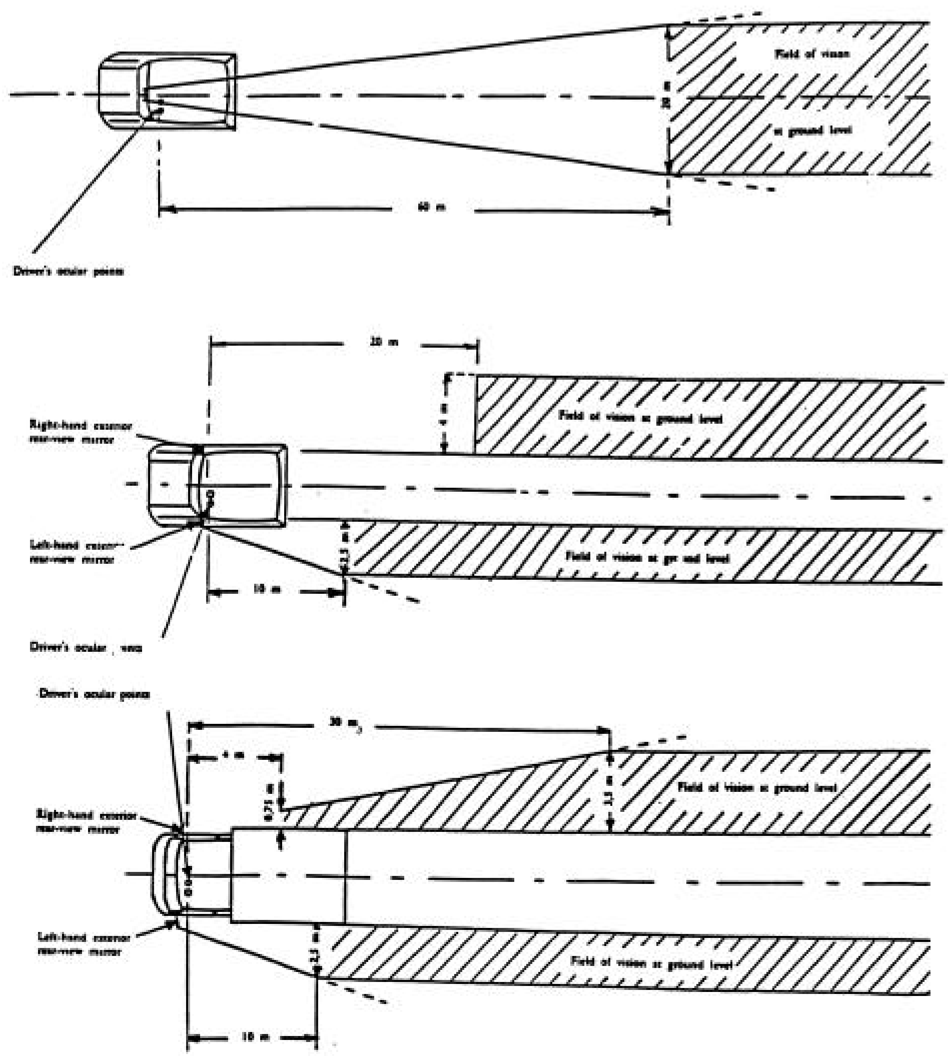

Figure 1 Required field of view interior mirror (top) and main exterior rearview mirrors (middle: vehicles up to 2 ton, bottom: vehicles over 2 tons)

Type-approval testing

Type-approval testing can be performed in any European country (EU member state or a country that acceded the ECE-agreement and signed the ECE-regulations). Other European countries, when admitting a certain car model, only verify that the vehicle and its components are approved. This implies that the type-approval testing data are dispersed over various type-approval bodies across Europe. The type-approval mark that is affixed on the protective housing of every rearview mirror contains three main items: the class of mirror (I = interior rearview mirror, II = main exterior mirrors for trucks and buses, III = exterior mirrors for cars) a code for the country in which the mirror was approved and the approval number. Based on this number, it is theoretically possible to trace the type-approval testing data from the relevant approval body.

However, these data mainly state whether or not the minimum criteria are met, so, for instance, it is registered that the specified areas behind the vehicle can be seen through the rearview mirrors, without measuring the total field of view. Due to the difficult accessibility of the type-approval data and the limited information content for the present study, this path was not further pursued to gather data on mirror characteristics.

Information from industry indicated that for a certain model of a certain car manufacturer there may be mirrors from different suppliers, each of them having a separate type-approval. Moreover, there may be a variation of mirror type within a certain model, e.g. for the Opel Astra mirrors are supplied by at least four mirror manufacturers in both spherical convex, aspherical and even planar mirror type. Mirrors are submitted for type-approval by the mirror housing manufacturer. The mirror housing manufacturers obtain the mirror glass from mainly three large mirror manufacturers in Europe.

2.2 Mirror characteristics of vehicles on the road

2.2.1 Method

The analysis of the mirror characteristics of vehicles on the road was based on the data that were gathered in Phase 1B of the study. In Phase 1B of the project a survey was made regarding, amongst other things, the strategies drivers use and the problems they encounter with different types of mirrors (Chapter 3). In order to relate the respondents' opinions to the type of mirrors on their cars, the characteristics of their rearview mirrors were registered. In this section the mirror data of this sample are presented.

A spherometer was used to measure the radii of curvature of the mirror surfaces. For each mirror, measurements were made on three points: in the middle of the mirror surface, as far as possible to the inside and as far as possible to the outer side of the reflecting surface. Although aspherical mirrors were primarily identified by the presence of a thin etched line marking the transition between the spherical part and the aspherical part, the three curvature measurements allowed a check for aspherical mirrors.

For the sample of 47 drivers who were interviewed in the first stage of Phase 1B not only the exterior mirrors were measured but also the interior mirrors. As all interior mirrors were found to be planar, in the second stage of Phase 1B only the exterior mirrors were considered.

For the second stage of Phase 1B, respondents were approached at a gas station and at a McDonald's Mcdrive restaurant. It is believed that these locations attract a broad spectrum of road users resulting in a reasonably representative sample. In total two hundred people completed the questionnaire. The questionnaire survey aimed at more or less equal samples of drivers with planar, spherical convex and aspherical mirrors. Furthermore, within each of these groups, comparable numbers of younger drivers and older drivers were aimed at. This was achieved by randomly sampling the first half of the respondents, and after categorization of this random sample, the other half of the respondents was approached more specifically to achieve a more or less equal filling of the mirror type x age group cells. For the purpose of the inventory of mirror types (percentages of planar, spherical convex and aspherical mirrors) the random sample gave a representative impression of the mix of mirror types. For the analysis of the mirror characteristics within a mirror type (i.e. the radius of curvature for spherical convex mirrors and the radius of curvature for the spherical part of aspherical mirrors), the full sample was used.

2.2.2 Results

2.2.2.1 Distribution of mirror types

Composition of different mirror types was analyzed for 96 randomly selected cars. Table 1 gives a breakdown of the proportion of vehicles with a certain mirror type for the driver's side mirrors and the passenger's side mirrors.

Table 1 Percentages of mirror types for driver's side mirror and passenger's side mirror (n=96).

		Passenger's side mirror				
		None	Planar	Spherical	Aspherical	Total
Driver's side mirror	Planar	0%	3.1%	39.6%	0%	42.7%
	Spherical	3.1%	0%	31.3%	0%	34.4%
	Aspherical	0%	0%	20.8%	2.1%	22.9%
	Total	3.1%	3.1%	91.7%	2.1%	100%

The results show that, at the moment this sample was taken, 57% of the cars on the road had non-planar driver's side mirrors. Of these non-planar mirrors 60% was spherical convex and 40% was aspherical.

The majority of passenger's side mirrors is spherical convex. Planar passenger's side mirror's only occur in combination with a planar driver's side mirror. Similarly, aspherical passenger's side mirrors only occur in combination with aspherical driver's side mirrors.

The distribution of driver's side mirror types in time (registration year of the vehicle) for the random sample is given in Figure 2. It can be seen that from the second half of the eighties a substantial proportion of cars was equipped with spherical mirrors. Aspherical mirrors were becoming more and more common over the last three years.

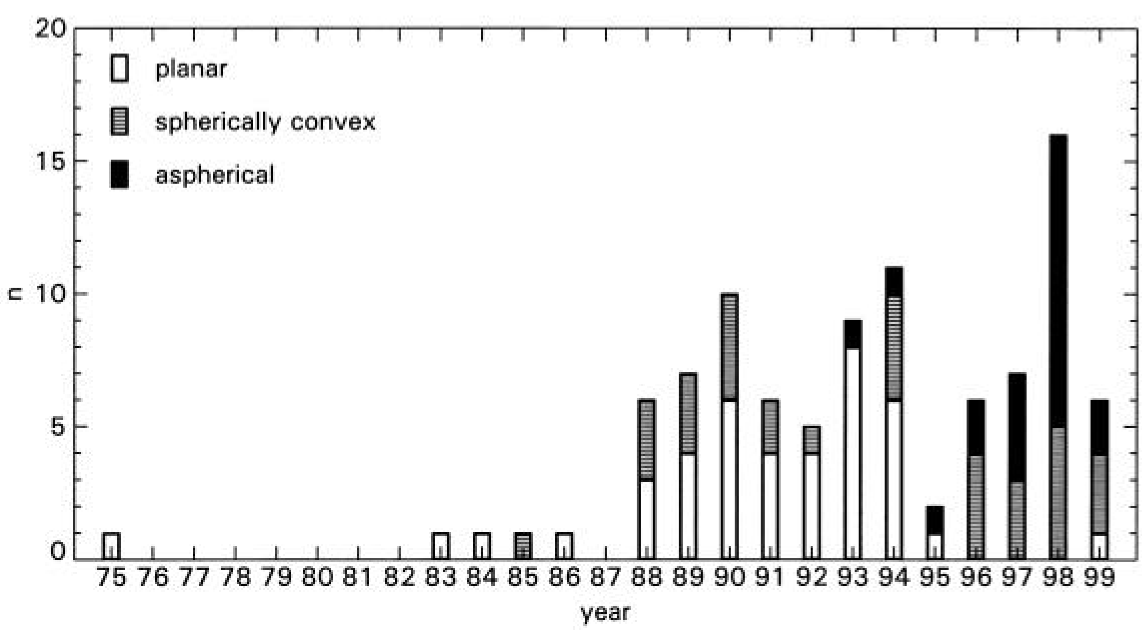

Figure 2 Distribution of driver's side mirror types versus year of car registration (n=96).

2.2.2.2 Radii of curvature non-planar mirrors

For the analysis of the radii of curvature of the non-planar mirrors the complete sample of 209 questionnaire respondents was taken into account.

Spherical driver's side mirrors

Figure 3 shows the distribution of the radii of curvature for spherical driver's side mirrors. Clear peaks can be distinguished around 1400 mm and 2000 mm. Furthermore, mirrors were found with radii of curvature in the range between 3000 and 4500 mm. A scatter plot of the curve radii versus the year of registration of the cars is given in Figure 4. There were no apparent trends over the years.

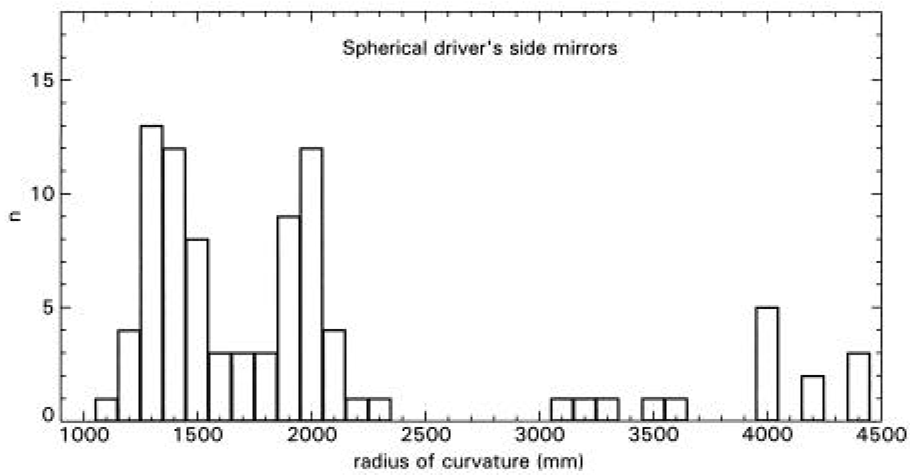

Figure 3 Distribution of radii of curvature for spherical driver's side mirrors (n= 89).

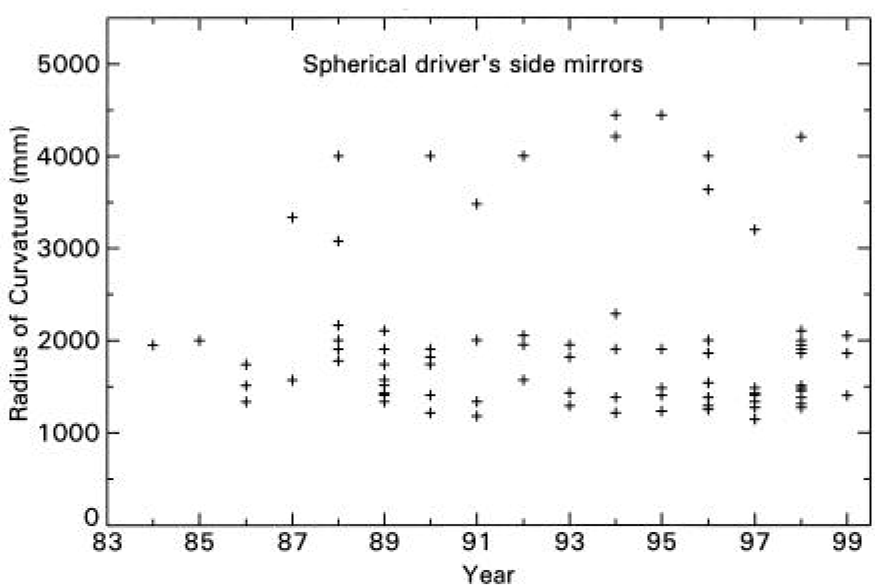

Figure 4 Scatter plot of radii of curvature versus year of registration of the vehicle for spherical driver's side mirrors (n= 89).

Aspherical driver's side mirrors

The distribution of radii of curvature for the spherical part of aspherical mirrors is given in Figure 5. A pronounced peak can be observed around 2000 and 2100 mm. Furthermore, some aspherical mirrors had a radius of curvature in the region from 1300 to 2000 mm. Radii of more than 2500 mm were not observed. The scatter plot of radius of curvature against year, see Figure 6, shows that over the past ten years radii were clustered around 2000 mm, while since 1998 also smaller radii in the order of 1400 mm were found.

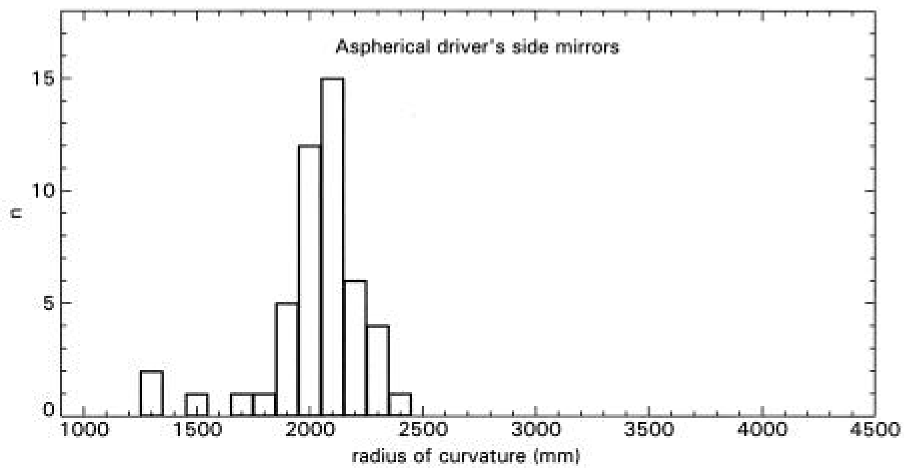

Figure 5 Distribution of radii of curvature for aspherical driver's side mirrors (n= 48).

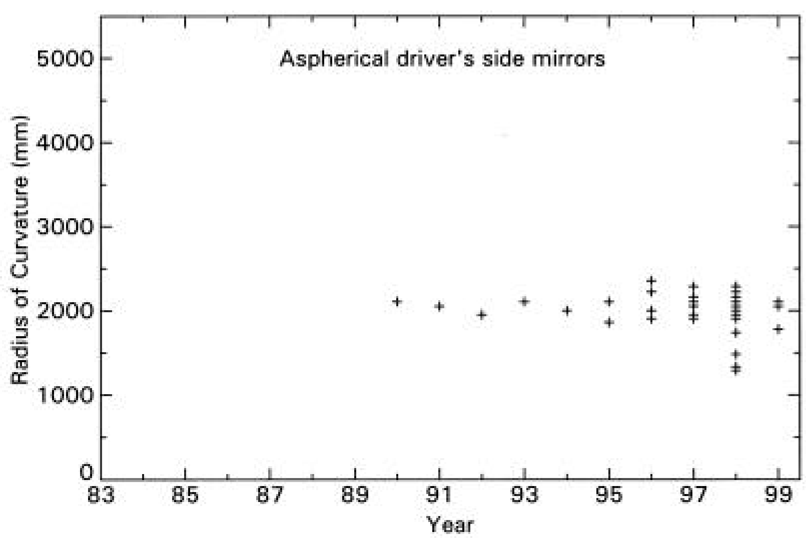

Figure 6 Scatter plot of radii of curvature versus year of registration of the vehicle for aspherical driver's side mirrors (n= 48).

Spherical passenger's side mirrors

Figure 7 indicates that spherical passenger's side mirrors showed the highest peak at 1400 mm, while also a clear peak was observed at 2000 mm. Radii larger that 2300 mm were not observed. One car had a radius of curvature of 1000 mm, which is below the allowed value according to the ECE-regulations. More detailed inspection showed that this car was imported from the United States. The scatter plot of radii of curvature versus time, see Figure 8, suggests that the dominance of 1400 mm radii over 2000 mm radii increased during the years.

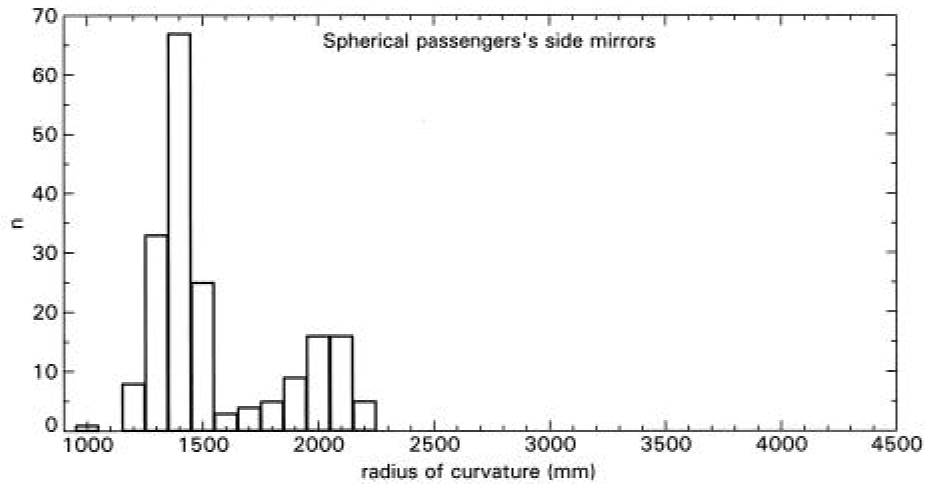

Figure 7 Distribution of radii of curvature for spherical passenger's side mirrors (n= 192).

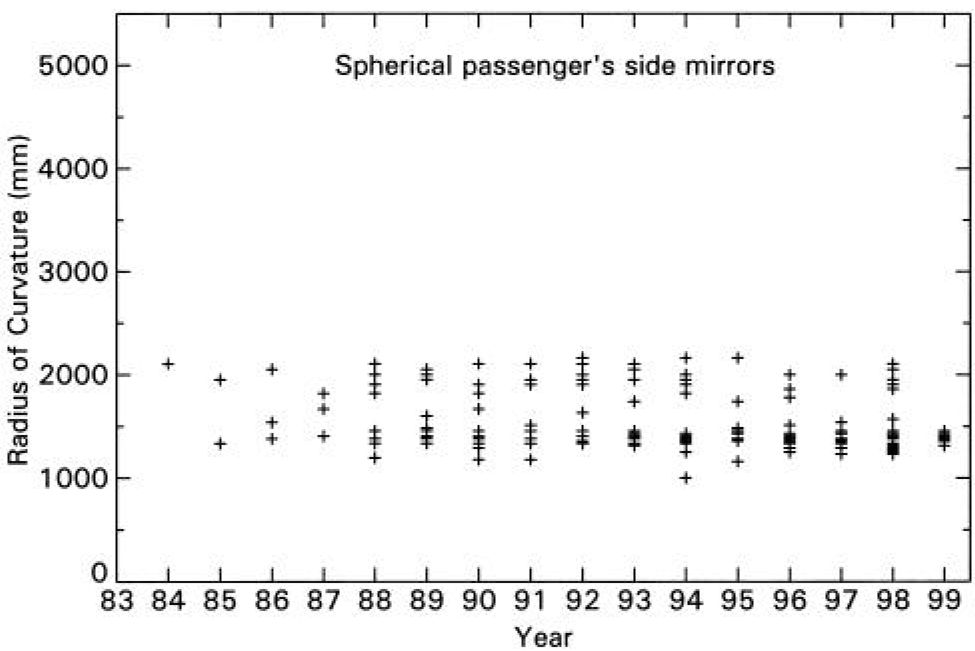

Figure 8 Scatter plot of radii of curvature versus year of registration of the vehicle for spherical passenger's side mirrors (n= 192).

Aspherical passenger's side mirrors

The radii of curvature of the spherical part of aspherical passenger's side mirrors were all found within one cluster around 2000 mm, see Figure 9. The scatter plot versus time (Figure 10) shows that aspherical passenger's side mirrors were not found before 1997.

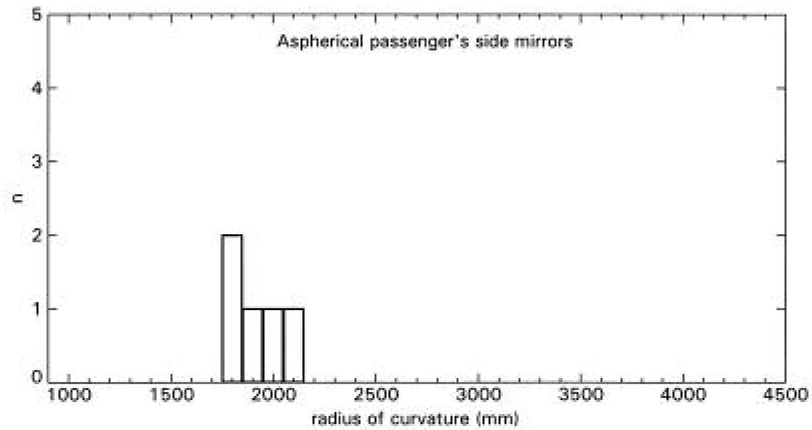

Figure 9 Distribution of radii of curvature for aspherical passenger's side mirrors (n= 5).

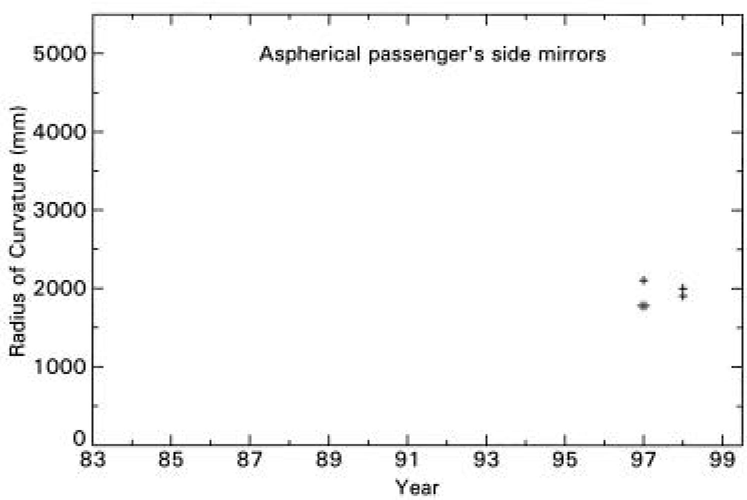

Figure 10 Scatter plot of radii of curvature versus year of registration of the vehicle for aspherical passenger's side mirrors (n= 5).

2.3 Mirror characteristics and field of view of recent cars

2.3.1 Method

Rearward fields of view were measured using the method described by Riemersma, Moraal and Van den Bos (1985) and applied by Verwey (1994). Each vehicle was positioned with the driver's eye point in the center of a 'field of view circle' drawn on the road. For the present study a field of view circle with a radius of 10 m was drawn. The distance along the circle was marked at a resolution of 20 cm. The intersection point between the field of view circle and a line through the eye point position parallel to the longitudinal axis of the vehicle was used as zero reference. The boundaries of the field of view were determined by moving a pole along the circle. The pole was held in upright position and moved along the circumference of the circle by one person, while another person in the driver's seat indicated whether the pole was visible through the mirrors or not.

Furthermore, in case of aspherical mirrors, the boundaries between the spherical part and the aspherical part were registered. Observations were made with both eyes, resulting in the ambinocular field of view (combination of the monocular fields of view for left eye and right eye). The fields of view for two persons, one shorter (1.68) and one longer (1.87 m), were registered and averaged. The fields of view for the outer mirrors were measured for two mirror positions: first the mirrors were aligned in such a way that the rear edge of the vehicle was just visible. Secondly, the outer mirrors were turned outward as far as allowed by the adjustment mechanism. Furthermore, the positions of the mirrors with respect to the eye point were registered, as well as the width and height of the mirror glass and the radius of curvature (ROC).

2.3.2 Results

The mirror characteristics and the resulting rearward field of view were determined for a sample of nine recent cars. In this sample the five best sold cars in the Netherlands for 1997 [CBS, 1998] were included, see Table 2. Furthermore, four other characteristic vehicles were included in the sample:

- a large sedan: Mercedes E200 (1997)
- an imported car from the United States: Toyota Camry (1997)
- a space wagon (Minivan): Chrysler Voyager, imported from Canada (1998)
- a van: Ford Transit (1997). This van has double outer mirrors on both sides: main mirrors with wide angle mirrors below.

Table 2 Top five of cars registered in the Netherlands, in 1997 [CBS, 1998].

		Number of cars registered in 1997	Number of cars on the road per 1-1-1998
All cars		468 319	5 931 387
I	Opel Astra	20 655 (4.4%)	167 499 (2.8%)
II	VW Golf	20 126 (4.3%)	317 848 (5.3%)
III	VW Polo	17 162 (3.7%)	99 495 (1.6%)
IV	Ford Escort	13 612 (2.9%)	241 079 (4.1%)
V	Ford Mondeo	12 225 (2.6%)	56 200 (0.9%)

The resulting fields of view for the nine vehicles are illustrated in Appendix A. In these drawings the edges of the field of view on the circle circumference are connected to the position of the mirror. It should be noted that the resulting angles are not the exact fields of view as the virtual eye point should be used instead of the mirror position, however the differences are small.

Table 3 gives the mirror characteristics of the driver's side mirror and the passenger's side mirror for the sample of nine vehicles. Interior mirrors of all vehicles were planar. The dimensions of the inner mirrors were very similar: the average width was 223.3 mm (standard deviation 18.6 mm) and the average height was 59.8 mm (standard deviation 3.6 mm). The five popular European cars all had non-planar outside rearview mirrors. Spherical mirrors had a radius of curvature of 1400 mm, while aspherical mirrors had a radius of curvature of 2000 mm. Three of those cars had aspherical driver's side mirrors. An aspherical mirror on the passenger's side was only found on the large sedan. The two cars imported from North America, both had planar driver's side mirrors, while the passenger's side mirrors were spherical convex, one with a radius of 1500 mm and one width a radius of 1000 mm. The latter one does not comply with the minimum radius of curvature of 1200 mm stipulated by the ECE-regulations.

The average field of view for the two planar driver's side mirrors (15°) is much smaller than the fields of view for the non-planar mirrors. The fields of view for the aspherical driver's side mirrors (average 29°) are not much larger than for spherical mirrors (26°). This can be explained by the fact that the radius of curvature of spherical mirrors is smaller (1400 mm) than the radius of curvature of the spherical part of aspherical mirrors (2000 mm). Thus, in case of comparable dimensions, the spherical part of the aspherical mirrors gives a smaller field of view than spherical mirrors, however the combination of the spherical part and aspherical part of the aspherical mirrors results in a field of view which is comparable to the field of view of a spherical mirror. It may be expected that due to the trend in the radius of curvature of aspherical mirrors from 2000 mm to 1400 mm, fields of view of aspherical mirrors will become substantially larger that the field of view of spherical mirrors. However, it should be noted that this trend will also allow designers to reduce the mirror dimensions to some extent giving greater freedom in styling and aerodynamics. So, there may be a trade-off between field of view (smaller radius of curvature in combination with unchanged mirror dimensions gives a larger field of view) on the one side and aesthetics and fuel efficiency (smaller radius of curvature in combination with unchanged field of view allows reduction of the mirror dimensions) on the other side. For the five aspherical mirrors in the current sample, the width of the aspherical part of the mirror is 27% (standard deviation 1.7%) of the total width of the reflecting surface.

There is some variation in the dimensions of the driver's side mirror reflecting surface and in the distance between the eye point and the mirror. The ratio of driver's side mirror width and distance is very constant for the five popular cars: 0.2.

2.4 Conclusions and recommendations on mirror characteristics

The sample of vehicles on the road showed that 43% had planar driver's side mirrors, 34% spherical convex mirrors and 23% aspherical mirrors. Passenger's side mirrors are predominantly spherical convex (92%). The distribution of the radii of curvature of driver's side spherical convex mirrors showed peaks around 1400 mm and 2000 mm, whereas also some mirrors were found with a radius of curvature in the range of 3000 to 4500 mm. For the radius of curvature of aspherical driver's side mirrors a peak was found around 2000 and 2100 mm, whereas a peak around 1400 mm was found for cars which were registered since 1998. For spherical convex passenger's side mirrors a dominant peak was found at 1400 mm, whereas a second peak was found at 2000 mm. The aspherical passenger's side mirrors all had a radius of curvature of about 2000 mm. Except for one American import car all radii were larger than the limit of 1200 mm as specified by the ECE-regulations. Although aspherical mirrors were mainly introduced on high end cars, the top five of cars registered in 1997 showed that aspherical mirrors are now also common on popular medium-size and small cars. Fields of view for the non-planar mirrors within the sample of nine cars were almost twice as large as the planar mirrors. Due to the larger radius of curvature for the aspherical mirrors (2000 mm) when compared to the spherical mirrors (1400 mm), the fields of view of the aspherical mirrors were only slightly larger.

For the experimental part of the study it was planned to include three mirror types: planar, spherical convex and aspherical. Based on the results of the inventory it was recommended to include a spherical mirror with a radius of curvature of 1400 mm, which proves to be the most common radius of curvature. For the aspherical mirror a radius of curvature of 2000 mm was recommended. Furthermore, it was recommended to add an aspherical mirror with a radius of 1400 mm. On the one hand this anticipated on future developments in mirror characteristics and on the other hand it would allow a more pure comparison between the effects of spherical and aspherical mirrors, without the confounding effect of the difference in radius of curvature. However, one of the main factors of the experiment was "experience with a certain mirror type" and it would have been very difficult to find subjects that had experience with aspherical mirrors with a radius of curvature of 1400 mm. Therefore, four mirror types could be included (planar, spherical 1400 mm, aspherical 1400 mm and aspherical 2000 mm) with three 'experience groups' (experience with planar mirrors, experience with spherical convex mirrors and experience with aspherical convex mirrors).

Table 3 Mirror characteristics of the driver's side mirror (lefthand mirror: columns marked 'L') and passenger's side mirror (righthand mirror: columns marked 'R') for nine characteristic cars.

Type: Type of mirror: p = planar, s = spherical convex, a = aspherical convex
ROC: Radius of curvature [mm]
FOV: Field of view [degrees]. The FOV is determined for the mirror when aligned in such a way that part of the own vehicle is visible. For the aspherical mirrors, the field of view for the spherical part is indicated between brackets.
W: Width of the total mirror surface [mm]
W_{asph}: Width of the aspherical part of the mirror surface [mm]
D: Distance between the driver's eye point and the center of the mirror [mm]
H: Height of the mirror surface [mm]

		Type		ROC [mm]		FOV [°]		W [mm]		W_{asph} [mm]		W_{asph}/W		D [mm]		W/D		H		H/D	
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Opel Astra		a	s	2162	1455	28 (16)	20	168	168	42	-	0.25	-	860	1340	0.20	0.13	100	103	0.12	0.08
VW Golf		a	s	2105	1429	27 (17)	16	171	125	48	-	0.28	-	860	1290	0.20	0.10	98	102	0.11	0.08
VW Polo		a	s	2078	1455	28 (19)	20	155	155	41	-	0.26	-	749	1378	0.21	0.11	94	95	0.13	0.07
Ford Escort		s	s	1312	1250	26	21	140	140	-	-	-	-	726	1357	0.19	0.10	89	91	0.12	0.07
Ford Mondeo		s	s	1429	1482	26	20	160	160	-	-	-	-	864	1328	0.19	0.12	93	91	0.11	0.07
Mercedes E200		a	a	1839	1951	32 (21)	32 (13)	165	165	50	44	0.30	0.27	870	1355	0.19	0.12	90	95	0.10	0.07
Toyota Camry		p	s	-	1039	18	26	179	178	-	-	-	-	700	1341	0.26	0.13	100	102	0.14	0.08
Chrysler Voyager		p	s	-	1510	12	20	175	175	-	-	-	-	970	1535	0.18	0.11	120	120	0.12	0.08
Ford Transit	main	s	s	2051	1976	18	17	150	150	-	-	-	-	1004	1565	0.15	0.10	212	212	0.21	0.14
	wide angle	s	s	281	281	51	47	140	140	-	-	-	-	1004	1565	0.14	0.09	38	38	0.04	0.02

3 EXPLORATORY QUESTIONNAIRE ON MIRROR USAGE (Phase 1B1)

3.1 Rationale

This chapter describes results of Phase 1B1 in which information on mirror usage was gathered by means of an extensive questionnaire which was completed by a limited number of respondents of different age groups using different types of mirrors. The goal was to explore which hypotheses on the effects of non-planar mirrors are relevant and to explore whether drivers experienced any mirror-related problems that were not foreseen in the preparation phase of the project. The basic hypotheses were:

- Mirror type may influence which mirrors are used and how often they are checked. The large field of view of non-planar mirrors may reduce the need to use multiple mirrors or to look over one's shoulder, while on the other hand due to the reduced size of the image of non-planar mirrors, drivers may need to use the inner mirror more often in order to check the distance of vehicles that they have seen in their outside mirror.
- Mirror type may have an effect on subjective feeling of safety and confidence when changing lanes.
- Due to the image reduction of non-planar mirrors, mirror type may influence the ability to estimate distance and speed of vehicles approaching from behind.
- Mirror type may have an effect on how often mirrors have to be adjusted. Due to the larger field of view of non-planar mirrors they may be less sensitive to misalignment.
- Drivers may not be aware of the type of mirrors on their car and the characteristics of different types of mirrors.
- Non-planar mirrors may reduce the occurrence of blind spot conflicts.
- Non-planar mirrors may increase the occurrence of conflicts due to a wrong assessment of the distance and speed of a vehicle coming from behind.
- Age-related effects on visual and cognitive functions may interact with the expected effects of mirror types. On the one hand elderly people are more likely to have problems turning their heads, for which the wider field of view of non-planar mirrors could be a benefit. On the other hand the ability to focus on a reduced and distorted image may decrease with age, resulting more problems for elderly people using non-planar mirrors.

Based on the results of this limited scale survey, a revised questionnaire and sampling plan were proposed for a larger scale survey that is reported in Chapter 4.

3.2 Method

A structured list of questions was used to gather extensive information regarding mirror use habits, problems drivers experience, their awareness regarding mirror characteristics and background variables. In view of the exploratory nature of this present phase of the project, questions were worded in general terms in order to stimulate respondents to give spontaneous answers, not being influenced by the premises of the study. This elaborate questionnaire is given in Appendix B (translated version in English; original version was in Dutch). The aim was to gather information by means of interviews of about 20 younger and 20 older drivers. Drivers were approached in a parking lot of a furniture store, which is popular amongst a wide range of social and economic levels of the Dutch population. Respondents were randomly selected. In order to get a sufficient number of respondents, some older drivers were approached in addition. Altogether, the sample of drivers and their vehicles is believed to be reasonably representative for the Dutch population of car drivers. The characteristics of the mirrors on the respondents' cars were registered. Three categories of mirrors were discerned:

- Mirrors with an entirely planar surface,
- Mirrors with a spherical convex surface,
- Mirrors with an aspherical convex surface.

A spherometer was used to determine the radius of curvature of the respondent's rearview mirrors. In case of aspherical mirrors, the radius of curvature was measured on the spherical part of the mirror.

Analyses of variance (ANOVA) were performed on the ratings (five point scales) with factors 'driver's side mirror type' (planar, spherical, aspherical) and 'age' (young, old). On the responses to the multiple choice questions log-linear analyses were performed with design variables 'driver's side mirror type' (planar, spherical, aspherical) and 'age' (young, old). In order to check for general effects of mirror convexity the mirror types spherical and aspherical were collapsed in further analyses.

3.3 Results

3.3.1 Respondents

The number of respondents per cell of the exploratory questionnaire are given in Table 4, which shows a similar number of respondents in the planar mirror and spherical mirror cells. Only a small part of the sample had aspherical mirrors. Within the two age groups the average ages per cell were comparable.

Table 4 Respondents' age and sex per age group and mirror type

Type of driver's side rearview mirror	Respondents age group	
	Younger (age <= 50) (N = 25)	Older (age > 50) (N = 22)
Planar (N = 21)	N*total* = 12 N*male* =5 N*female* = 7 Average age = 35.0 Std dev age = 11.3	N*total* = 9 N*male* = 4 N*female* = 5 Average age = 65.1 Std dev age = 4.8
Spherical (N = 20)	N*total* = 10 N*male* = 6 N*female* = 4 Average age = 33.2 Std dev age = 8.0	N*total* = 10 N*male* = 6 N*female* = 4 Average age = 63.1 Std dev age = 8.4
Aspherical (N = 6)	N*total* = 3 N*male* = 2 N*female* = 1 Average age = 38.0 Std dev age = 3.0	N*total* = 3 N*male* = 2 N*female* = 1 Average age = 59.7 Std dev = 8.6

Table 5 lists the type of passenger's side rearview mirror for the three types of driver's side mirrors. For planar driver's side mirrors, the majority of passenger's side mirrors are spherical convex, while some cars still have no passenger's side mirror or a planar passenger's side mirror. Spherical convex driver's side mirrors are mostly combined with spherical convex passenger's side mirrors, while some still don't have a passenger's side mirror. Spherical convex driver's side mirrors were not found in combination with planar or aspherical passenger's side mirrors. Aspherical driver's side mirrors were combined with spherical convex (67%) or aspherical passenger's side mirrors. All inner mirrors were planar with the exception of one respondent who had a non-planar mirror attached over the standard inside mirror.

Further background variables
At the end of the questionnaire, respondents were asked to give some further background variables:

- 64% of the respondents wore glasses or lenses (question 40).

- One respondent (older, spherical driver's side mirror) reported having a limited field of vision (question 41) and reported wearing vari-focus glasses.
- 8.7% reported to suffer from car-sickness (question 42).
- One respondent (older, planar driver's side mirror) reported having difficulties turning her head due to a spinal operation (question 43).

Table 5 Overview of respondents' passenger's side rearview mirror characteristics for each driver's side rearview mirror type. For the non-planar mirrors the average radius of curvature (ROC) in millimeters is given as well as the standard deviation (Std dev).

Driver's side rearview mirror	Passenger's side mirror			
	None	Planar	Spherical	Aspherical
Planar	14% (n=3)	10% (n=2)	76% (n=16) ROC=1595 Std dev=576	-
Spherical ROC=2045 Std dev=931	15 % (n=3)	-	85% (n=17) ROC=1450 Std dev=221	-
Aspherical ROC=1900 Std dev=297	-	-	67% (n=4) ROC=1357 Std dev=33	33% (n=2) ROC=1576 (spherical part) Std dev=343

3.3.2 Mirror use

3.3.2.1 Mirror adjustment

Drivers were asked to indicate on a five point scale (from 1 'never' to 5 'always') whether they adjust their mirror alignment before driving (question 5). The average scores are indicated in Table 6 for the driver's side mirror, the inner rearview mirror and the passenger's side mirror. The results are given per age group and per driver's side mirror type.

Table 6 Rating of mirror adjustment frequency (1 = never, 5 = always).

Driver's side mirror type	Mirror adjustment frequency					
	Driver's side mirror		Inner mirror		Passenger's side mirror	
	Young	Old	Young	Old	Young	Old
Planar	3.5	3.7	3.8	3.4	2.7	2.8
Spherical	3.3	3.9	3.6	3.4	2.7	3.8
Aspherical	2.7	4.0	3.7	4.0	2.7	3.8

No effects on mirror adjustment frequency were found of either driver's side mirror type nor age group. There seemed to be a tendency that older drivers adjust their passenger's side mirror more often in case of non-planar driver's side mirrors (a difference in average frequency of one scale point). In general, the passenger's side mirror seemed to be adjusted less often than the inner mirror and the driver's side mirror.

The following comments with regard to mirror adjustment behavior were given:
- sole user (7 respondents)
- multiple users (12 respondents)
- right hand mirror is least needed
- automatically check
- depends whether adjustment was changed
- in order to get a good field of view
- backing from car park
- safety
- to check for traffic coming from behind
- always okay
- other traffic
- habit
- learned to check mirrors from the start
- fold mirror away when parking
- very stable setting
- only after usage by others

It seemed that the need for mirror adjustment strongly depends on whether or not there are other people using the same car, needing different adjustment. In the present exploratory questionnaire this was not explicitly asked. By explicitly asking about this aspect in the large sample questionnaire, separate analyses can be made for drivers that share a car with more users and for drivers that are sole users. As single users and multiple users were most likely not equally distributed amongst the mirror type x age groups in the present small sample, this difference was likely to dominate any effect of mirror type or age.

When respondents were asked whether they align their driver's side mirror in a certain way (question 6), the following aspects were mentioned:

Younger respondents

Planar driver's side mirror
- so I can see part of the car as a reference
- small part of the car visible, large part of the road to the left in order to see approaching traffic
- in such a way that I just don't see the side of my car
- have to be able to look along the car and to see traffic behind
- in relation to blind spot
- relatively far outward because of large blind spot
- in relation to additional blind spot mirror
- align in order to see traffic to the side and behind
- to see the road
- no (2x)

Spherical driver's side mirror
- so I can see part of the car as a reference (3x)
- small part of the car visible, large part of the road to the left in order to see approaching traffic
- a little further than 'seeing the backside'
- so I can see what is beside me
- see approaching traffic (2x)
- normal
- yes

- no

Aspherical driver's side mirror

- at a distance because of much highway driving, i.e. wide field of view
- align in order to see traffic to the side and behind
- see traffic behind

Older respondents

Planar driver's side mirror

- so I can see part of the car as a reference
- in relation to blind spot
- so I can see as much as possible of the road straight behind
- yes (2x)
- sometimes
- is always okay
- no

Spherical driver's side mirror

- so I can see part of the car as reference
- yes complementary to inner mirror
- such that the left lane is visible with a blind spot as small as possible
- such that the left lane is visible
- so I can see what is beside me
- so I can see that I am being overtaken
- yes (3x)
- yes, after purchasing a car, otherwise not

Aspherical driver's side mirror

- maximal field of view
- in relation to blind spot
- see traffic behind

Two strategies were mentioned several times in most groups: the alignment strategy in which a small part of the driver's own vehicle is visible as reference, and the alignment strategy to minimize the blind spots by turning the mirror as far as possible outward without overlap with the field of view of the inner mirror. Experiments that focussed on driving a vehicle based on a camera image have shown that vehicle references are used mainly in lateral tasks (curve driving and lane changes) while vehicle references did not play a role in distance estimation (Van Erp, 1995). For the use of rearview mirrors this may mean that aligning a mirror in such a way that part of one's own vehicle is visible provides the driver with information about the relative angle of an object observed via a mirror (this is especially relevant on multilane roads) while it is not expected that seeing part of one's own vehicle improves estimation of distance.

Many general statements about being able to see what is behind / besides the own car did not give a clear indication about the exact strategy, although they suggested that maximizing the field of view is seen as an important criterion.

3.3.2.2 Mirror use frequency

Drivers were asked to indicate on a five point scale (from 1 'never' to 5 'always') how frequently they use their driver's side mirror and inner mirror when overtaking or changing lanes to the left (question 7). The average scores are indicated in Table 7 for the inner rearview mirror and the driver's side mirror. The results are given per age group and per driver's side mirror type.

No main effects of age and mirror type were found. There seemed to be a tendency that younger drivers use their inner mirror more often in the case of non-planar driver's side mirrors. Older drivers use their inner mirror less often in case of a non-planar driver's side mirror. Younger drivers seemed to use spherical driver's side mirrors more often than planar mirrors, whereas older drivers seemed to use spherical driver's side mirrors somewhat less often.

Table 7 Rating of mirror use when overtaking or changing lanes to the left (1 = never to 5 = always).

Driver's side mirror type	Mirror use frequency			
	Driver's side mirror		Inner mirror	
	Young	Old	Young	Old
Planar	4.5	4.9	4.3	4.8
Spherical	4.8	4.7	4.9	4.6
Aspherical	5.0	4.7	5.0	4.6

A hypothesis could be that older drivers observe larger time margins in traffic (e.g. larger time headway, larger gaps (Van Winsum, 1996; Staplin, 1995)) and therefore mainly check for approaching vehicles, for which the non-planar driver's side mirrors provide more information than planar mirrors, resulting in less need for the inner mirror. Younger drivers may observe smaller margins, requiring accurate estimates of distance and approach speed, for which a check in the planar inner mirror is needed in case of non-planar driver's side mirrors.

The average responses to the question on the frequency (ranging from 1 'never' to 5 'always') of looking over one's shoulder (question 8) are given in Table 8.

Table 8 Frequency of looking over shoulder (1 = never, 5 = always).

Driver's side mirror type	Frequency of looking over shoulder	
	Young	Old
Planar	4.3	3.6
Spherical	4.3	3.4
Aspherical	4.0	4.0

Again no statistically significant main effects were found. However, when responses were collapsed over spherical and aspherical mirrors, there was a tendency that older respondents look over their shoulder less often [$F(1,43)=2.9$, $p<0.1$]. Concerning aspherical mirrors older respondents seemed to look more often over their shoulder in case of aspherical mirrors, whereas younger respondents seemed to look over their shoulder somewhat less often in case of aspherical mirrors.

Respondents were asked whether or not they thought they can safely pass another vehicle or change lanes to the left by looking only in their rearview inner mirror (question 9) or by looking only in their driver's side mirror (question 10). The results are given in Tables 9 and 10, respectively.

No main effects of age or driver's side mirror type were found. The majority of respondents felt they can not safely go to the left by just looking in one single mirror. A considerable amount (40%) of older drivers with spherical mirrors said they could safely go to the left with just the information of the driver's side mirror. Despite the large field of view of aspherical mirrors, only one respondent (young) with an aspherical driver's side mirror said that he/she can safely go to the left by just looking in the driver's side mirror.

Table 9 Percentage of respondents who indicated they can safely go to the left by only looking in their inner mirror.

Driver's side mirror type	% of respondents that said they can safely go to the left by only looking in their inner mirror	
	Young	Old
Planar	17	11
Spherical	0	20
Aspherical	0	0

Table 10 Percentage of respondents who indicated they can safely go to the left by only looking in their driver's side mirror.

Driver's side mirror type	% of respondents that said they can safely go to the left by only looking in their driver's side mirror	
	Young	Old
Planar	25	0
Spherical	20	40
Aspherical	33	0

Turn head to check blind spot

Respondents were asked to what extent they have to turn their head to check their blind spot (question 44). Results are given in Table 11 and illustrated in Figure 11.

Table 11 Extent to which respondents have to turn their heads to check blind spot (1 = hardly, 5 = fully turned).

Left hand mirror type	Extent to which respondents have to turn their heads to check blind spot	
	Young	Old
Planar	3.5	3.2
Spherical	3.0	2.4
Aspherical	2.0	2.3

A trend effect of mirror type was found [$F(2,41)=2.47$, $p<0.1$]. The extent to which respondents have to turn their heads reduced with increasing mirror convexity.

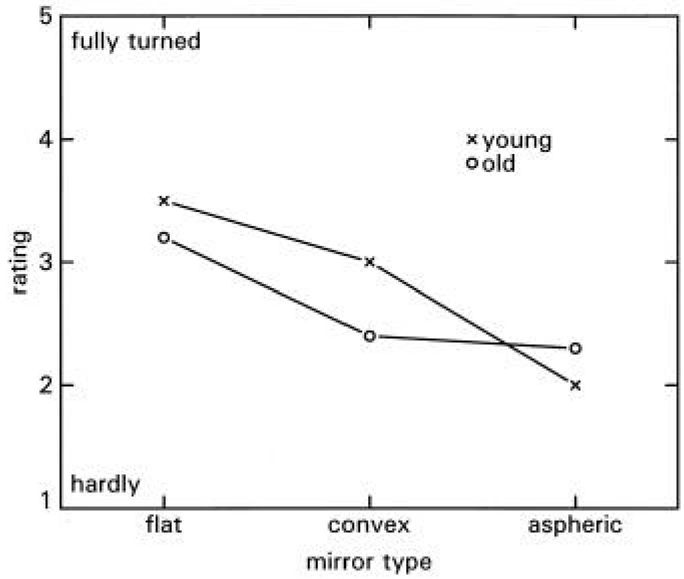

Figure 11 Extent to which respondents have to turn their heads to check blind spot.

3.3.2.3 Lane change criterion

Respondents were asked whether they use a specific criterion to decide whether they can overtake or not in case of heavy traffic behind them (question 11). The following comments were given:

Younger respondents

Planar driver's side mirror

- combination of looking at inner mirror and driver's side mirror and looking over shoulder
- first look in mirror, then look over shoulder, turn on indicator and finally change lanes
- first inner mirror, then outer mirror, then estimation of distance and then change lanes
- push the accelerator
- try to merge in such a way that traffic approaching from behind does not have to hit the brakes
- if a car is visible in the inner mirror and not yet visible in the outside mirror
- intuitive: I think speed of the approaching traffic is main factor; do trust distance in driver's side mirror better than inner mirror
- there has to be sufficient space to make this manoeuvre and it has to be of use
- no, only estimation of distance
- speed
- no
- in due time I show my intention to move to the left and I adapt my speed

Spherical driver's side mirror

- distance and speed of traffic approaching from behind (2x)
- speed of traffic approaching from behind in relationship to gap
- if there is a gap and there is sufficient room, then I go to the left
- yes there has to be sufficient space
- space between my car and the car on the left lane
- estimated speed and distance of traffic coming from behind and own speed and acceleration potential
- no, depends on traffic
- no, I just cut in

- no

Aspherical driver's side mirror

- estimating distance and speed of traffic approaching from behind (2x)
- speed

Older respondents

Planar driver's side mirror

- first driver's side mirror then inner mirror
- always look whether it is safe
- observe traffic approaching from behind for some time to learn speed difference and available space
- to make sure there is no hindrance for traffic coming from behind
- sufficient distance
- has to be ample space
- yes
- no

Spherical driver's side mirror

- at all occasions check inner mirror as well
- look in mirror whether lane change is possible
- sufficient space to merge in front of other traffic without bother
- there has to be sufficient distance
- speed of traffic approaching from behind
- same speed
- wait (a few seconds)
- it needs to be safe to my feeling, otherwise I do not overtake
- in case of doubt no action just wait
- no

Aspherical driver's side mirror

- inner mirror is frequently used; outside mirror is used to prepare manoeuvre
- need ample space
- distance and speed difference

The following items seemed to recur:

- the tradition sequence, as trained during driving lessons, of checking both mirrors and looking over one's shoulder.
- not causing any bother to traffic coming from behind
- checking distance and/or checking speed

A number of older respondents with spherical mirrors mentioned a conservative strategy not to change lane in case of uncertainty.

3.3.2.4 Perceived safety, confidence and trust

Perceived safety

There were no main effects of mirror type and age group on the ratings in response to the question how safe respondents feel when passing other vehicles or changing lanes to the left in heavy traffic (question 12). However an interaction of mirror type x age group was found [$F(2,41)=4.19$, $p<0.05$]. The average safety ratings are given in Table 12 and the interaction is illustrated in Figure 12. Older drivers with planar mirrors felt safe when changing lanes, while older drivers with non-planar mirrors felt less safe. In contrast, for younger drivers the feeling of safety increased with non-planar mirrors.

Table 12 Rating to which level respondents feel safe when passing other vehicles or changing lanes to the left in heavy traffic (1 = unsafe, 5 = safe).

Driver's side mirror type	Rating to which level respondents feel safe when changing lanes	
	Young	Old
Planar	3.8	4.7
Spherical	4.3	4.1
Aspherical	4.3	3.0

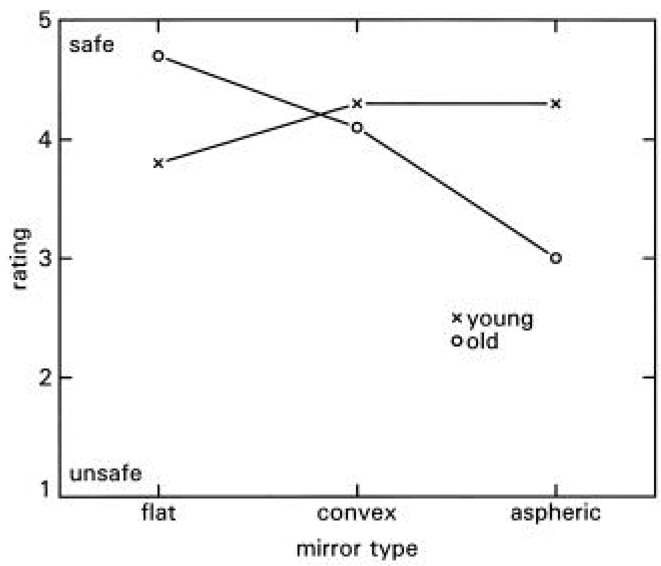

Figure 12 Rating on perceived level of safety when passing other vehicles or changing lanes to the left in heavy traffic (1 = unsafe, 5 = safe).

Confidence

A similar result was found for the question to what extent respondents feel confident when overtaking or changing lanes to the left (question 13, Table 13). Again, an interaction between mirror type and age was found [$F(2,41)=4.34$, $p<0.05$]. Older drivers with spherical mirrors feel less confident, while younger drivers feel more confident, as illustrated in Figure 13.

Table 13 Rating of degree respondents feel confident when passing other vehicles or changing lanes to the left in heavy traffic (1 = uncertain, 5 = confident).

Driver's side mirror type	Rating of degree respondents feel confident when changing lanes	
	Young	Old
Planar	3.8	4.7
Spherical	4.3	4.2
Aspherical	4.7	3.3

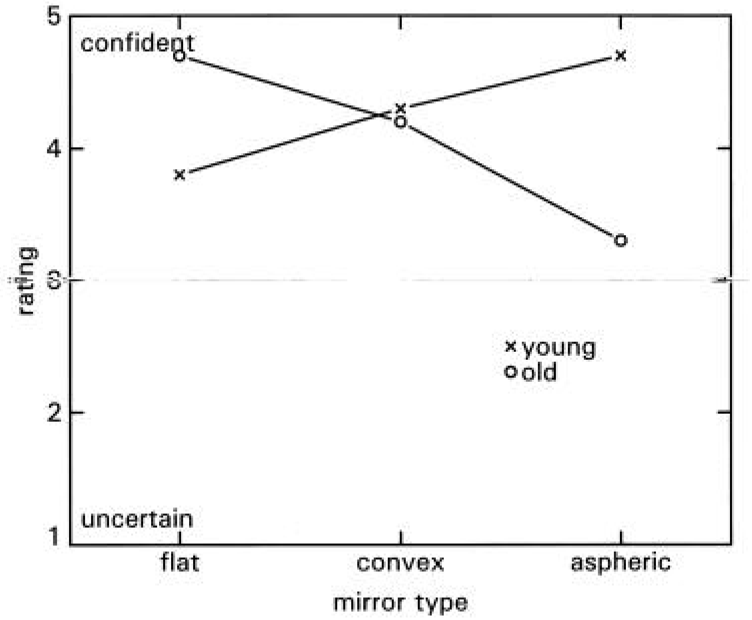

Figure 13 Rating on perceived level of confidence when passing other vehicles or changing lanes to the left in heavy traffic (1 = uncertain, 5 = confident).

Trust in mirror information

Respondents were asked whether they trust the information received via the inner mirror and via the driver's side mirror (question 14, Table 14). No significant effects of age or mirror type were found. The averages seemed to indicate that mainly in the limited sample of aspherical mirrors there was a deviation between older and younger respondents: older drivers with aspherical mirrors seemed to have less trust in their mirrors, while younger drivers with aspherical mirrors had more trust.

Table 14 Rating of trust in information respondents receive via mirrors (1 = distrust, 5 = trust).

Driver's side mirror type	Rating of trust in mirror information			
	Driver's side mirror		Inner mirror	
	Young	Old	Young	Old
Planar	4.0	3.9	4.4	4.4
Spherical	4.3	4.0	4.3	4.3
Aspherical	4.7	3.0	4.7	3.3

3.3.2.5 Estimation of distance and speed and frequency of checking

Respondents were asked to rate whether they are able to properly estimate distance and speed of cars coming from behind (question 15, Table 15). With respect to the estimation of distance a trend effect of age was found [$F(1,41)=3.17$, $p<0.1$], that is, young respondents felt better able to estimate distance than older respondents (Figure 14). No significant main effect of mirror type was found. No significant effects for estimating speed were found, although the averages showed the same tendencies as found for the estimation of distances.

Table 15 Rating of the ability to estimate distance and speed of cars coming from behind (1 = badly, 5 = very well).

Driver's side mirror type	Estimation			
	Distance		Speed	
	Young	Old	Young	Old
Planar	4.3	4.4	4.2	4.3
Spherical	4.3	4.0	4.0	3.8
Aspherical	5.0	3.7	4.7	3.3

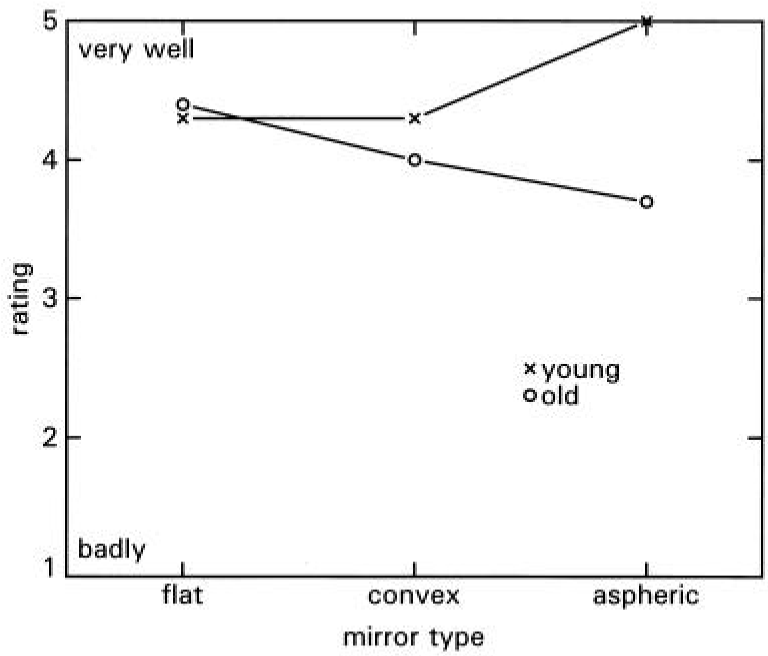

Figure 14 Rating of the difficulty of estimating distances of cars coming from behind.

With respect to differences in the difficulty of estimating the distance and speed of vehicles coming from behind during daylight or darkness (question 16) the results are given in Table 16.

No significant effects of age or mirror type were found. Roughly one third of the respondents reported no difference between daylight and darkness, two thirds found it easier to estimate speed and distance during daylight and hardly any respondent found it easier to assess vehicles coming from behind during darkness.

Table 16 Differences in difficulty of estimating distance and speed of vehicles coming from behind during daylight or darkness.

Age group	Left hand mirror type	Difficulty estimating distance and speed during daylight or darkness (% per age x mirror group)		
		No difference	Easier in daylight	Easier in darkness
Young	Planar	8.3	83.3	8.3
	Spherical	40	60	0
	Aspherical	33	67	0
Old	Planar	37.5	62.5	0
	Spherical	30	70	0
	Aspherical	33	67	0

Frequency of checking

Participants were asked whether they check once or several times when they look into the driver's side mirror (question 17) (Table 17). No effects of age or mirror type were found.

Table 17 Responses on the question whether participants check driver's side mirror once or several times.

Age group	Left hand mirror type	Frequency of checking driver's side mirror (% per age x mirror group)		
		Do not check	Look once	Look several times
Young	Planar	0	25	75
	Spherical	0	20	80
	Aspherical	0	0	100
Old	Planar	11	11	78
	Spherical	0	20	80
	Aspherical	0	0	100

Similarly, respondents were asked whether they look over their shoulder once or several times before going to the left (question 18) (Table 18). No effects of age or mirror type were found.

Table 18 Responses on the question whether participants check over their shoulder once or several times when going to the left.

Age group	Left hand mirror type	Frequency of looking over shoulder (% per age x mirror group)		
		Do not check	Look once	Look several times
Young	Planar	8.3	50	41.7
	Spherical	10	70	20
	Aspherical	0	67	33
Old	Planar	22.2	44.4	33.3
	Spherical	40	40	40
	Aspherical	0	67	33

Use of inner mirror to check outside mirror assessment

Respondents were asked whether they use their rearview inner mirror to check whether a car in the driver's side mirror is far enough behind (question 28). The distribution of responses per age x mirror type group is given in Table 19.

Table 19 Distribution of responses (%) per age x mirror type group for using inner mirror to check distance of a car in driver's side mirror.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
Yes	100	75	67	77.8	90	100
No	0	25	33	22.2	10	0

Some comments were given. Twice, respondents (both young, one with a planar mirror and one with a spherical mirror) mentioned that they first look in their inner mirror and then check in their driver's side mirror. One respondent mentioned that if a car is visible in the driver's side outer mirror he/she does not go to the left.

No effects of age or mirror type were found on using the inner mirror to check the distance of a car in the driver's side mirror.

3.3.2.6 Conflicts

Blind spot conflicts

Table 20 indicates how often respondents reported it happened that a car was in their blind spot when they overtook or changed lanes to the left (question 19). Furthermore, this Table indicates the seriousness of the situation in case such conflicts occurred (question 20).

Table 20 Frequency of car in blind spot when changing lanes to the left (1= never, 5 = often) and seriousness of situation (1 = not serious, 5 = serious).

Left hand mirror type	Frequency of car in blind spot when changing lanes to the left		Seriousness of situation	
	Young	Old	Young	Old
Planar	2.7	2.6	2.1	1.3
Spherical	2.1	2.5	2.0	1.8
Aspherical	1.7	2.3	1.5	1.3

No main effects of age and mirror type were found on the occurrence of conflicts with a car in the blind spot nor on the severity of conflicts. The average frequency seemed to decrease with increasing mirror convexity.

With respect to the cause of the conflict (question 21) the following items were ticked:
- the car beside/behind was driving too fast (13x)
- I was driving too fast (0x)
- I did not look in my mirror (2x)
- I did not look over my shoulder (11x)
- I saw the car, but made an improper assessment (2x)
- I did look in my mirror, but did not see the other car (21x)

Further items that were mentioned are:
- not sufficiently anticipated
- car behind changed speed
- was distracted by conversation
- car coming from behind was driving too fast
- car changed lane
- raindrops on lefthand frontwindow and driver's side outer mirror
- motorcycle was not visible in mirrors

Conflicts due to wrong assessment of car coming from behind

Table 21 indicates how often respondents reported it happened that while changing lanes respondents made a wrong assessment of the speed of a car coming from behind and moved to the left while they shouldn't (question 22). Furthermore, this Table indicates the seriousness of the situation in case such conflicts occurred (question 23).

Table 21 Frequency of wrong assessment of car coming from behind (1= never, 5 = often) and seriousness of situation (1 = not serious, 5 = serious).

Left hand mirror type	Frequency of wrong assessment of car coming from behind		Seriousness of situation	
	Young	Old	Young	Old
Planar	2.1	2.0	1.5	2.3
Spherical	2.1	2.2	1.6	1.9
Aspherical	2.0	1.7	1.7	1.5

No main effects of age and mirror type were found on the occurrence of conflicts due to a wrong assessment of a car coming from behind nor on the severity of conflicts.

With respect to the cause of the conflict (question 24) the following items were ticked:
- The car beside/behind was driving too fast (17x)
- I was driving too fast (0x)
- I did not look in my mirror (2x)
- I did not look over my shoulder (3x)
- I saw the car, but made an improper assessment (12x)
- I did look in my mirror, but did not see the other car (6x)

Further items that were mentioned are:
- The other car did not pay attention
- Have not driven in a sufficiently anticipating manner

3.3.2.7 Mirror use when stepping out of a car, backing and pulling away

Respondents were asked whether they check their mirrors and/or look over their shoulder when stepping out of their car (question 25). The results are given in Table 22.

Table 22 Checking of mirrors and looking over shoulder when stepping out of one's car as a relative percentage per age x mirror type group.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
1=Inner mirror	8.3	0	0	0	0	0
2=Driver-side mirror	8.3	10	0	22.2	20	66
3=Shoulder	16.7	10	33	11.1	50	0
1+2	0	0	33	11.1	0	0
1+3	0	10	0	22.2	0	0
2+3	66.7	50	33	22.2	10	0
1+2+3	0	20	0	11.1	20	33

Respondents were asked whether they check their mirrors and/or turn their head when backing into a parking space (question 26). The results are given in Table 23.

Table 23 Checking of mirrors and turning head when backing into a parking space as a relative percentage per age x mirror type group.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
1=Inner mirror	0	0	0	0	10	0
2=Driver-side mirror	0	10	0	11.1	0	0
3=Turn head	0	30	0	36.4	20	50
1+2	0	0	0	9.1	10	0
1+3	16.7	20	33	27.3	10	0
2+3	50.0	20	33	0	10	50
1+2+3	33.3	20	33	0	40	0

Respondents were asked whether they check their mirrors and/or look behind when pulling away from the side of the road (question 27). The results are given in Table 24.

Table 24 Checking of mirrors and looking behind when pulling away from the side of the road as a relative percentage per age x mirror type group.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
1=Inner mirror	8.3	10	0	0	10	0
2=Driver-side mirror	0	0	0	0	10	33
3=Turn head	0	10	0	0	0	0
1+2	8.3	10	33	44.4	20	66
1+3	0	0	0	22.2	0	0
2+3	41.7	50	33	33.3	10	0
1+2+3	41.7	30	33	0	50	0

No effects of age or mirror type on mirror use when stepping out of one's car, backing or pulling away were found.

3.3.2.8 Awareness of mirror characteristics

Respondents were asked whether they noticed something peculiar about the driver's side mirror of their present car (question 29). The responses are given in Table 25.

Table 25 Distribution of responses (%) per age x mirror type group when asked whether respondents noticed something peculiar about their driver's side mirror.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
No	66.7	100	0	77.8	50	0
Yes	33.3	0	100	22.2	50	100

A main effect of mirror type was found [χ^2=9.06 (df=2) p<0.05]. Especially respondents with aspherical mirrors noticed that their mirrors are special. It is remarkable that younger respondents with spherical mirrors did not consider those mirrors as being special.

The following peculiarities were mentioned:

Younger respondents

planar
- small extra mirror in right upper corner
- blind spot
- large blind spot
- distorts image

spherical

-

aspherical
- reduces image
- convex
- aspherical

Older respondents

planar
- blind spot
- is folded in

spherical
- aspherical
- position is too high
- reduces image
- you have to get used to the new mirrors because they are deceiving
- not everything can be seen

aspherical
- double mirror
- aspherical mirror
- fracture/plane at an angle for enlargement of the field of view

It seemed that especially drivers with aspherical mirrors are aware that they have some kind of special mirrors. However, the exact characteristics were not always clear to them.

Respondents were asked whether they noticed any difference between their driver's side mirror and the inner mirror (question 30). The responses are given in Table 26.

Table 26 Distribution of responses (%) per age x mirror type group when asked whether respondents noticed any difference between their driver's side mirror and their inner mirror.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
No difference	8.3	20	0	11.1	10	0
Yes, there is a difference	66.7	80	100	33.3	80	67
Don't know	25	0	0	55.6	10	33

A trend effect of mirror type was found [χ^2=5.78 (df=2) p<0.1]. A considerable proportion of the respondents with non-planar mirrors was aware of a difference.

The following differences were mentioned:

Younger respondents

planar

- different glass (reduces image)
- different images
- inner mirror gives view behind, driver's side mirror gives field of view to the side, but not in blind spot
- distance of traffic coming from behind looks different
- inner mirror gives total view of traffic coming from behind, driver's side mirror gives view of overtaking traffic: different field of view
- inner mirror gives better overview

spherical

- magnifying
- driver's side mirror distorts distance
- overlap in field of view
- bad visibility via inner mirror due to plastic rear window
- different view of backward situation
- reduces image
- difference in size
- outside mirror reduces image

aspherical

- one reduces image, the other does not (inner mirror)
- convex part
- aspherical

Older respondents

planar

- blind spot remains
- heated and electrically adjustable
- different fields of view

spherical

- fields of view complement each other
- mine is properly adjusted
- use of inner mirror provides better view of traffic coming from behind
- outside mirror reduces image, inner mirror does not
- large field of view mirror inside

- distance (blind spot)
- none of the two mirrors gives a complete view of the situation

aspherical
- shape, inner mirror not double
- outside mirror is aspherical

The differences that were mentioned by respondents with planar mirrors were to a large extent referring to the different fields of view of the inner mirror and the outer mirror. Against expectations a few respondents with planar mirrors reported a difference in image size. In case of non-planar mirrors the aspects image reduction and image distortion were mentioned but these aspects were not dominant in the responses.

Respondents were asked whether there was a difference between the driver's side mirror of their present car and that of their previous car (question 31). The responses are given in Table 27.

Table 27 Distribution of responses (%) per age x mirror type group when asked whether respondents noticed any difference between the driver's side mirror on their present car and their previous car.

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
No difference	54.5	80	67	75	70	33
Yes, there is a difference	36.4	20	33	12.5	30	67
Don't know	9.1	0	0	12.5	0	0

No effects of age or mirror type on the reported difference between present and previous mirror were found.

The following differences were mentioned:

Younger respondents

planar
- extra mirror
- smaller mirror
- previous car (Suzuki Alto 1987) had no blind spot

spherical
- driver's side mirror gave better indication of distance
- in Volvo (other car is Volvo 940 built in 1992) you can see blind spot (distortion)

aspherical
- aspherical

Older respondents

planar
- previous mirror was not heated, and was not electrically adjustable

spherical
- previous mirror did not reduce image
- cars coming from behind are nearer than one would think
- better overview

aspherical
- aspherical outside mirror

- present mirror: fracture/plane at an angle; heating

Respondents' knowledge on mirror characteristics

Respondents were asked if they knew whether their driver's side mirror is planar, spherical, aspherical (question 34). The results are given in Table 28.

Table 28 Respondents' awareness of the characteristics of their driver's side mirror (percentages per age x mirror type group).

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
Planar	75	60	33	55.6	40	33
Convex; constant radius (Spherical)	25	10	0	0	30	0
Convex; varying curvature (aspherical)	0	0	67	0	10	33
Don't know	0	30	0	44.4	20	33

No effects of age or mirror type were found.

45% of all respondents accurately knew what type of mirror they had. 23% of the respondents said they did not know what kind of driver's side mirror they had. Only 6% of the respondents mistakenly answered their mirror was non-planar while in fact it was planar. In contrast, 26% of the respondents answered that their mirror was planar though it was non-planar.

Respondents were asked if they knew what the difference between planar and convex mirrors is (question 35). The results are given in Table 29.

Table 29 Percentage of respondents that stated they did know the difference between planar and convex mirrors.

Driver's side mirror type	Percentage of respondents that stated they did know the difference between planar and convex mirrors	
	Young	Old
Planar	66.7	44.4
Spherical	80	70
Aspherical	67	100

No effects of age or mirror type were found, however, the averages suggested that respondents with non-planar mirrors were more aware of the difference between planar and convex mirrors than respondents with planar mirrors.

The following differences were mentioned:

Younger respondents

planar

- reduces image, larger area can be seen
- distorts image
- larger field of view in case of convex mirrors
- different refraction, different / more angles
- convex mirror gives wider field of view
- with a convex mirror one can see blind spot, with planar mirror one does not
- convex mirrors distort image but give a better field of view
- convex mirror provides larger field of view to the side

spherical

- magnification / reduction
- wider field of view
- convex mirrors give wider field of view
- larger viewing field of view
- you can see blind spot
- convex mirror gives more overview
- difference in size reproduction and consequently distance

aspherical

- wider field of view (2x)

Older respondents

planar

- image is distorted and reality does not correspond with image
- a convex mirror has a larger field of view
- somewhat wider field of view

spherical

- convex mirror increases image
- convex mirror provides larger and better field of view
- distortion
- resembles carnival mirror
- image is smaller and thus more complete
- convex mirror gives distorted (smaller) image

aspherical

- convex mirrors give a larger field of view, however they also distort the image
- road behind can be seen
- enlarges/reduces

The main items that were mentioned are:

- reduced image
- distorted image
- wider field of view, reduced blind spots

3.3.2.9 Transition from previous to present mirrors

Respondents were asked whether they had any problems getting used to the driver's side mirror of their new car (question 32). The results are given in Table 30.

Table 30 Rating of difficulty in getting used to driver's side mirror on new car (1= not difficult, 5 = very problematic).

Driver's side mirror type	Rating of difficulty in getting used to driver's side mirror	
	Young	Old
Planar	4.6	4.6
Spherical	4.9	4.9
Aspherical	5.0	4.3

No main effects of age or mirror type were found on the reported difficulty in getting used to the driver's side mirror of their new car. Judging from the averages, the difficulty in getting used to new mirrors seemed to slightly increase with increasing mirror curvature both for younger and older drivers. However, the older drivers with aspherical mirrors showed the opposite. Any conclusions on the difficulty of the transition are limited by the fact that the type of mirrors on the previous cars could not be traced. It was remarkable that the ratings for all types of mirrors, including planar mirrors were high. This might mean that the differences between cars in mirror dimensions, mirror position and the external dimensions require quite some adaptation irrespective of mirror type.

Respondents were asked whether they prefer the driver's side mirror on their present car or their previous car (question 33). The results are given in Table 31 (1 = previous car, 5 = is present car).

Table 31 Rating of preference for previous or present driver's side mirror (1= previous, 5 = present).

Driver's side mirror type	Preference for previous or present driver's side mirror	
	Young	Old
Planar	3.3	3.3
Spherical	3.1	3.4
Aspherical	5.0	5.0

A main effect of driver's side mirror type was found [$F(2,33)=3.76$, $p<0.05$]. No main effect of age was found. Most notable is the high preference for aspherical mirrors (see Figure 15).

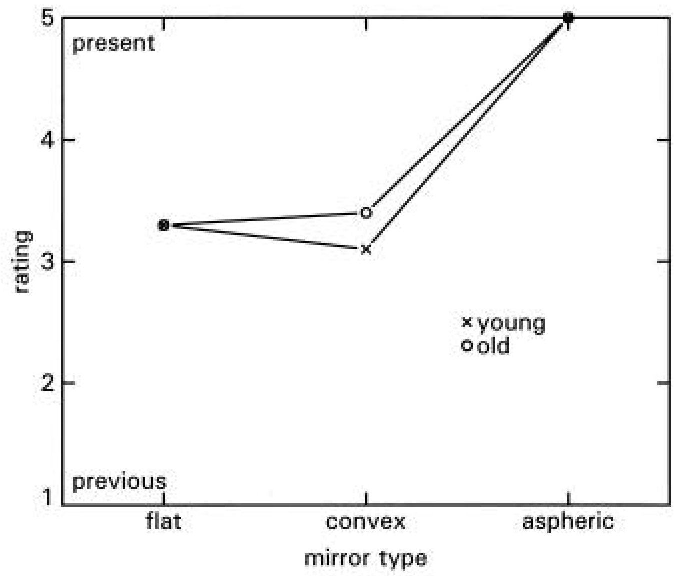

Figure 15 Rating of preference for previous or present driver's side mirror (1 = previous, 5 = present).

3.3.2.10 Use of aspherical mirrors

The respondents that had aspherical driver's side mirrors were asked to complete three questions concerning the use of these mirrors (question 36). In Table 32 the responses are indicated.

Table 32 Responses of drivers with aspherical mirrors concerning the use of these mirrors.

		Young	Old
Certain strategy when using aspherical mirror?	Yes	1	1
	No	2	1
Different use of inner and outer part?	Yes	2	2
	No	1	1
Can you go to the left if a car is visible in the outer part?	Yes	-	-
	No	3	3

One younger respondent gave as strategy that beyond the thin line it means unsafe, too close.
The three respondents that reported a difference in use of the inner part and the outer part gave the following explanation:
use of the inner part: distance (young respondent) standard (old),
use of the outer part: blind spot (2 younger respondents) in slow traffic (old).

3.3.2.11 Role of mirrors when buying a new car

Respondents were asked whether they pay attention to the rearview mirrors when buying a new car (question 37). Table 33 gives the results per age x mirror type group.

Table 33 The role of rearview mirrors when buying a new car (percentage per age x mirror type group).

	Young			Old		
	Planar	Spherical	Aspherical	Planar	Spherical	Aspherical
Do not pay attention to rearview mirrors	41.7	70	33	11.1	20	33
Do pay attention, but does not affect choice	50	30	33	45.5	60	67
Rearview mirrors do play a role in choosing a car	8.3	10	33	27.3	10	0

Age and mirror type had no effect on the role of mirrors when buying a new car. 37% of the respondents said they do not pay attention to the mirrors when buying a new car, 48% do pay attention but it does not play a role in the decision and 15% said the mirrors do play a role in choosing a car.

3.3.2.12 Additional rear vision devices

Respondents were asked whether they had any additional devices to improve the field of view besides and behind your car, other than the rearview mirrors (question 38).

The following responses were given:

Younger respondents

planar

- Separate **convex** mirror attached in the corner of the left outside mirror (2x)

spherical

- Separate **convex** mirror attached in the corner of the left outside mirror

aspherical

-

OLD

planar

- Separate **convex** mirror attached in the corner of the left outside mirror

spherical

- large field of view inner mirror (attached over the standard inside mirror)

aspherical

- rear headrests folded down in case the rear seats are unoccupied

Other devices such as a Fresnel lens ('Fishbowl'sheet) on the rear window were not represented in the current survey population.

3.3.2.13 Accident involvement

Respondents were asked whether they had been involved in an accident in the past five years (question 39). 28% of the respondents had been involved in an accident in the past five years. From those accidents 46% took place in their present car. 23% of the accidents were potentially mirror-related. Two respondents reported mirror-related accidents with their present car (of which the mirror type is known): one young respondent with a spherical driver's side outer mirror reported having had an accident by running into another car when pulling away from a parking space, one older respondent with a spherical mirror reported having had an accident due to a blind spot when backing into a parking space.

3.4 Discussion and conclusions exploratory questionnaire

In this section the findings based on the exploratory questionnaire are summarized and the recommendations for the revised questionnaire are discussed.

Adjustment
There seemed to be a tendency that older drivers adjust their passenger's side mirrors more often in case of non-planar driver's side mirrors. Passenger's side mirrors seem to be less often adjusted than inner mirrors or driver's side mirrors (question 5: Q5). A likely factor influencing the need for mirror adjustment is whether a car is driven by one or more users. In the revised questionnaire a question was added concerning whether respondents are (almost) the only one driving the car or there are others also driving this car. This question allowed a more detailed analysis regarding the need for mirror adjustment depending on the type of mirror.

Two alignment strategies recurred in most age and mirror type groups, i.e. a strategy in which a small part of driver's own vehicle is visible as a reference and an alignment strategy to minimize the blind spots by turning the mirror as far as possible outward without overlap with the field of view of the inner mirror (Q6). For the revised questionnaire the general question on whether respondents use a certain strategy when adjusting their mirror was replaced by a multiple choice question with the options: - I align the driver's side mirror such that a small part of my own vehicle is visible as a reference, - I align the driver's side mirror outward such that there is as little as possible overlap with the inner mirror, resulting in a minimum blind spot, - other, ...

Use frequency
There seemed to be a tendency that younger drivers use their inner mirror more often in case of non-planar driver's side mirrors. Older drivers use their inner mirror less often in case of a non-planar driver's side mirror. Younger drivers seemed to use spherical driver's side mirrors more often than planar mirrors, whereas older drivers seemed to use spherical driver's side mirrors somewhat less often (Q7).

Looking over shoulder
There was a tendency that older drivers look over their shoulder less often in case of non-planar driver's side mirrors. It seemed that older drivers with aspherical mirrors look over their shoulder more often whereas younger drivers with aspherical mirrors look over their shoulder less often (Q8). Drivers tend to turn their head to a lesser extent in case of increasing mirror convexity (Q44).

Combined use of mirrors
Most drivers indicated that they can not safely go to the left by using either just the inner mirror or just the driver's side mirror (Q9 & Q10). From this response it was not possible to determine the reason for employing this strategy: either (1) drivers may need a combination of mirrors and looking back only to check for vehicles behind and beside the vehicle or (2) in order to obtain an accurate estimation of speed and distance drivers may check the speed and distance of an approaching vehicle seen in the driver's side mirror by means of the undistorted and unreduced image of the inner mirror. When specifically asked for (Q28) a vast majority of drivers said that they use their inner mirror to check the distance of a car seen in the outer mirror. Although one might expect that there is more need to check the distances as seen in the reduced image of a non-planar mirror than there is to check the image of a non-reduced planar outside

mirror, the present sample does not give any indications of an effect of mirror type. Similarly an effect of age could be expected in the sense that older drivers observe larger margins and therefore have less need for an accurate assessment of distance and approach speed, while on the other hand older drivers might check more thoroughly in order to compensate for reduced skills in perceiving distance and approach speed.

It was proposed to combine the questions on looking frequency, combined use of mirrors, looking over one's shoulder, and checking outer mirror by means of inner mirror into three questions: - Which information do you use to check for vehicles behind?; Which information do you use to check for vehicles beside your car?; Which information do you use to assess speed and distance of vehicles approaching from behind?. On all three question ratings on a five-point scale from 'never' to 'always' are asked for the 'inner mirror', the 'driver's side mirror' and 'looking over one's shoulder'.

Perceived safety, confidence and trust
Questions on whether respondents felt safe (Q12) and confident (Q13) when changing lanes showed an interaction between age and mirror type. Younger drivers feel more safe and confident in case of non-planar mirrors, while older drivers feel less safe and confident with increasing mirror convexity. The present sample did not reveal an effect of age or mirror type on trust in the mirror information, although it seemed that the trust in the mirror information is increased for younger drivers with aspherical mirrors while it is decreased for older drivers with aspherical mirrors (Q14). It was proposed to maintain these questions in the revised questionnaire.

Estimation of speed and distance
Younger drivers felt better able to estimate the distance of a vehicle in the rearview mirrors than older drivers. From the average ratings it seemed that both estimation of distance and estimation of speed improves with mirror convexity for younger drivers while it seems to deteriorate for older drivers (Q15). Other results (Staplin, 1995) showed that older drivers mainly face problems in estimating speed due to reduction with age of the eye sensitivity to visual expansion. On the question of whether light condition plays a role in estimating speed and distance through the mirrors (Q16), one third said there is no difference, while two thirds of drivers said it is easier in daylight. No indications for any interactions with age or mirror type were found.

In the proposal for the field experiment, the main hypothesis to be tested concerns the effect of mirror type on estimation of distance and speed and the expected interaction with age. Therefore it was proposed to maintain the question on estimating speed and distance. Differences between light conditions were incorporated in the revised questionnaire by asking two responses on the questions relating to trust in the mirror information and relating to perceived safety: one response for daylight conditions and one response for darkness.

Frequency of checking
The results did not give indications of possible effects of mirror type and age on the frequency of checking one's mirror (Q17) or checking over one's shoulder (Q18) when going to the left. The majority of drivers checked their mirror several times, while about equal proportions of the respondents checked over their shoulder once and check several times. A minority of the respondents said they do not check over their shoulder. As these questions did not reveal any unexpected tendencies and they have the aspect of looking frequency in common with question 5, it was proposed to drop these questions.

Conflicts
Although no statistically significant effects of age and mirror type were found, the occurrence of conflicts involving a vehicle in a blind spot seemed to decrease with increasing mirror convexity (Q20), which is in line with the hypothesis that the larger fields of view provided by non-planar mirrors reduce blind spot conflicts. No indications for potential effects of age or mirror type were found with respect to conflicts due to a wrong assessment of the speed of a vehicle coming from behind (Q22). It was proposed to

maintain the questions on the occurrence of conflicts in order to see if a larger sample would reveal any effects of mirror type on the (perceived) frequency of conflicts.

Mirror use when stepping out of a car, backing and pulling away
No effects were found of mirror type or age on mirror use when stepping out of one's car (Q25), backing into a parking space (Q26) or pulling away from the side of the road (Q27). It was proposed to drop these questions in the revised questionnaire.

Mirror awareness
The results showed that drivers with non-planar mirrors were to some extent aware of the characteristics of their mirrors. When asked whether there is a difference between the inner mirror and the driver's side mirror (Q30), unexpectedly also drivers with a planar driver's side mirror reported a difference between the inner mirror and the driver's side mirror. Most comments given by this group referred to the difference in field of view. Only a few of these drivers with planar mirrors mentioned an image reduction of the driver's side mirror.

About half of the respondents accurately knew what type of driver's side mirror they had (Q34). A quarter said they did not know. The most frequent mistake was that drivers with a non-planar mirror mistakenly thought it was planar. Only a few drivers with planar mirrors thought their mirror to be non-planar. The considerable proportion of drivers who either mistakenly thought their non-planar mirror was planar, or who did not know if their mirror was planar or non-planar, gives rise to some concern. However, drivers may compensate for the image reduction of non-planar mirrors even without being consciously aware of the mirror characteristics.

When asked about the differences between planar and convex mirrors (Q35) many respondents mentioned a larger field of view, image reduction and image distortion.

Concerning awareness of mirror characteristics it was proposed to merge these questions into two multiple choice questions. One question on image reduction and distortion and one question asking whether respondents know what type of mirror they have:

Transition from previous to present car
No effects of mirror type or age were found with regard to the difficulty of getting used to the mirror on one's new car (Q32). When asked whether drivers preferred the driver's side mirror on their present car or on their previous car (Q33), the preference for the present mirror was higher for non-planar mirrors. Especially the aspherical mirrors received high ratings. Unfortunately, the mirror characteristics of a driver's previous car could not be traced. Consequently it was not known which type of mirrors were compared. In the revised questionnaire it was asked how long it had taken the repondents to get used to their present driver's side mirror. Furthermore it was asked whether they preferred a planar, spherical or aspherical mirror. Reliable information on the effect of a change in mirror-type will be derived in phase 2 of the study (field experiment).

Use of aspherical mirrors
Drivers with aspherical mirrors mentioned some differences in use of the spherical part of the mirror and the aspherical part (Q36). The purpose of the aspherical part was said to be for checking blind spots. Unanimously, respondents said they could not go to the left when a car was visible in the aspherical part of the mirror. As only a very small sample of driver's with aspherical mirrors was represented in the exploratory study it was proposed to maintain this question in the larger sample survey.

Role of mirrors when buying a new car
Neither the type of mirror drivers currently use nor the age of the driver had an effect on the attention paid to mirrors when buying a new car (Q37). Only 15% of the respondents said that mirrors play a role in the choice of a new car. About half the respondents said they do take notice, while 37% said they do

not pay any attention to mirrors when buying a new car. This question was not included in the revised questionnaire.

Appendix C gives the questionnaire (English version; original version was in Dutch) which was revised according to the considerations given above. The main purpose of the large scale questionnaire was to gather a substantial data sample on those items that showed to be interesting in the exploratory questionnaire study. The added value of the large sample questionnaire survey will be the increase of statistical power with respect to the exploratory questionnaire and a broader representation of drivers and driving experiences. For this purpose the questionnaire was streamlined in order to reduce the time needed to complete the questionnaire.

In summary, the results of the exploratory questionnaire showed that:

- When changing lanes older drivers look over their shoulder less often than younger drivers,
- The extent to which drivers turn their head reduces with increasing mirror convexity,
- When changing lanes, younger drivers feel more safe and confident in case of non-planar mirrors, while older drivers feel less safe and confident in case of non-planar mirrors,
- Younger drivers feel to be better able to estimate distance than older drivers,
- Especially drivers with aspherical mirrors are aware of the special characteristics of their mirrors,
- Half the respondents accurately knew what type of mirror they had (67% correct for planar mirrors, 20% correct for spherical mirrors and 50% correct for aspherical mirrors), a quarter said they did not know, a quarter thought they had a planar driver's side mirror, while in fact it was convex and only a very small proportion thought the mirror was convex while it was planar.
- Drivers with non-planar mirrors have a higher preference for their present mirrors when compared to their previous mirrors than drivers with planar mirrors.

In general, the differences between older and younger respondents that were found in the exploratory study confirmed that the factor age had to be taken into account in the further phases of the study. Furthermore, the results confirmed that there are differences in use and preferences between planar driver's side mirrors, spherical convex mirrors and aspherical mirrors.

The results indicated that maximizing field of view / minimizing blind spots is a much appreciated added value of non-planar mirrors, however at the same time image reduction and distortion is recognized as a disadvantage. Given the potentially improved detection of objects in the area behind and beside the car as a result of non-planar mirrors, the proposed focus of the initial project plan was confirmed, i.e. to see to what extent the image reduction and distortion has an effect on the estimation of distance and approach speed of vehicles coming from behind.

3.5 Proposed sampling plan for the revised questionnaire

In the original proposal it was planned to send the large sample questionnaire out to 400 respondents. Given the fact that it was basically impossible to determine the mirror characteristics (for example based on car type, model and year) without actually measuring the characteristics of the mirror mounted on the vehicle, an alternative approach was suggested. By approaching respondents in person at a location where their car was available (parking lot or gas station) the mirror characteristics could be registered. As this approach was more time consuming than sending out questionnaires by mail it was proposed to adapt the sample size to this method. For both methods the amount of useful responses may be comparable, because only a limited proportion of the people that receive a questionnaire by mail complete and return the forms, whereas the direct approach has a response rate near to 100%. The large sample questionnaire was given to about 200 drivers.

4 LARGE SAMPLE QUESTIONNAIRE ON MIRROR USAGE (Phase 1B2)

In Phase 1B, following the first exploratory stage (Phase 1B1: Chapter 3 of this report and also de Vos, Theeuwes & Perel (1999)), a questionnaire was used to gather information from a larger sample of drivers. The present Chapter gives the results of this second stage 'Questionnaire survey', i.e. Phase 1B2. Based on the results of Phase 1B1 a revised questionnaire was designed. A number of questions was combined and questions were rephrased from exploratory and open questions to more precisely worded multiple choice questions.

4.1 Method

The revised questionnaire (see Appendix C for a translated version in English; the original version of the questionnaire was in Dutch) was used to gather data from a large sample of drivers regarding mirror use habits, problems drivers experience, their awareness regarding mirror characteristics and background variables. Respondents were approached directly in order to be able to measure the characteristics of the rearview mirrors on their car (phase 1A learned that directly measuring the mirror characteristics is more efficient than trying to trace the mirror type of a given model of car of a given year afterwards via industry or via type approval registration).

Respondents were approached at a gas station and at a McDonald's McDrive restaurant. It is believed that these locations attract a broad spectrum of road users resulting in a reasonably representative sample. The aim was to gather data of about 200 respondents with a more or less equal representation of drivers with planar driver's side mirrors, spherical convex mirrors and aspherical mirrors. Furthermore, within each of these groups, comparable numbers of younger drivers and older drivers were aimed at. This was achieved by randomly sampling the first half of the respondents, and after categorization of this random sample, the other half of the respondents was approached more specifically to achieve a more or less equal filling of the mirror type x age group cells.

The characteristics of the mirrors on the respondents' cars were registered. Three categories of mirrors were discerned:

- Mirrors with an entirely planar surface,
- Mirrors with a spherical (constant radius) convex surface,
- Mirrors with an aspherical (varying radius) convex surface.

A spherometer was used to measure the radii of curvature of the respondent's rearview mirrors. For each mirror, measurements were made on three points: in the middle of the mirror surface, as far as possible to the inside and as far as possible to the outer side of the reflecting surface. Although aspherical mirrors were primarily identified by the presence of a thin etched line marking the transition between the spherical part and the aspherical part, the three curvature measurements allowed a check for aspherical mirrors. In case of aspherical mirrors, the measurement on the spherical part of the mirror was considered for the further calculation of the radius of curvature.

4.2 Results

4.2.1 Respondents

The number of respondents per cell of the questionnaire survey are given in Table 34. All cells were well filled, however the unequal representation of mirror types and age groups was still apparent in the number of respondents in the different cells. Although the main skewness of the representation of mirror types and age groups was compensated for by a partially stratified sampling approach, younger drivers were still better represented than older drivers and aspherical mirrors were outnumbered by planar and spherical mirrors. Within the two age groups, the average ages per cell were comparable.

Table 34 Respondents' age and sex per age group and mirror type.

Type of driver's side rearview mirror	Respondents age group	
	Younger (age <= 50) (N = 116)	Older (age > 50) (N = 92)
Planar (N = 71)	N*total* = 37 N*male* = 24 N*female* = 13 Average age = 34.9 Std dev age = 8.7	N*total* = 34 N*male* = 24 N*female* = 10 Average age = 63.9 Std dev age = 9.4
Spherical (N = 89)	N*total* = 53 N*male* = 32 N*female* = 21 Average age = 37.1 Std dev age = 8.7	N*total* = 36 N*male* = 22 N*female* = 14 Average age = 63.5 Std dev age = 8.9
Aspherical (N = 48)	N*total* = 26 N*male* = 23 N*female* = 3 Average age = 37.6 Std dev age = 8.5	N*total* = 22 N*male* = 15 N*female* = 7 Average age = 60.4 Std dev age = 9.5

Table 35 lists the type of passenger's side rearview mirror for the three types of driver's side mirrors. A detailed analysis of the rearview mirror characteristics of the present sample is given in Chapter 2.

Table 35 Overview of respondents' passenger's side rearview mirror characteristics for each driver's side rearview mirror type. For the non-planar mirrors the average radius of curvature (ROC) in millimeters is given as well as the standard deviation (Std dev).

Driver's side rearview mirror	Passenger's side mirror			
	None	Planar	Spherical	Aspherical
Planar	1% (n = 1)	6% (n = 4)	93% (n = 66) ROC = 1558 Std dev = 322	-
Spherical ROC = 2012 Std dev = 917	8% (n = 7)	-	92% (n = 82) ROC = 1593 Std dev = 291	-
Aspherical ROC = 2017 Std dev = 215	-	-	88% (n = 42) ROC = 1442 Std dev = 197	12% (n = 6) ROC = 1945 (spherical part) Std dev = 150

Further background variables
At the end of the questionnaire, respondents were asked to give some further background variables:

- 83% of the respondents almost always drove the car they were driving when they completed the questionnaire, 17% drove various cars. One respondent used to drive another car than the car driven when the questionnaire was completed. This respondent was disregarded for the analysis.

- 73% of the respondents were the only person driving their car. 27% shared the car with other drivers.
- 2.4% of the respondents were non-Dutch.
- 62% of the respondents wore glasses or lenses.

4.2.2 Mirror adjustment

Drivers were asked to indicate on a five point scale (from 1 'never' to 5 'always') whether they adjust their mirror alignment before driving. Subjects gave a response for the inner mirror, the driver's side mirror and the passenger's side mirror. In the analysis of the responses it was taken into account whether or not the respondent was the only person driving the car or whether there were more people driving the same car.

The results were submitted to an Analysis of Variance (ANOVA) with factors 'driver's side mirror type' (planar, spherical convex, aspherical convex), 'age group' (young, old), 'number of users' (single user, various users) and 'mirror position' (inner mirror, driver's side mirror, passenger's side mirror). A main effect of the mirror position was found [$F(2,372)=14.23$, $p<0.001$]. The number of users showed a marginally significant effect [$F(1,186)=3.37$, $p<0.1$]. Furthermore, there was a marginally significant interaction between number of users and mirror position [$F(2,372)=2.98$, $p<0.1$]. Similar to the results of the exploratory study, no main effects on mirror adjustment frequency were found of either driver's side mirror type nor age group.

The interaction between the number of users and mirror position is illustrated in Figure 16. The inner mirror is most frequently adjusted (average rating 3.1). The driver's side mirror ranks second (average rating 2.9) and the passenger's side mirror is least adjusted (average rating 2.6). Shared use of a car increases the mirror adjustment frequency (average ratings single users 2.7 versus shared use 3.1).

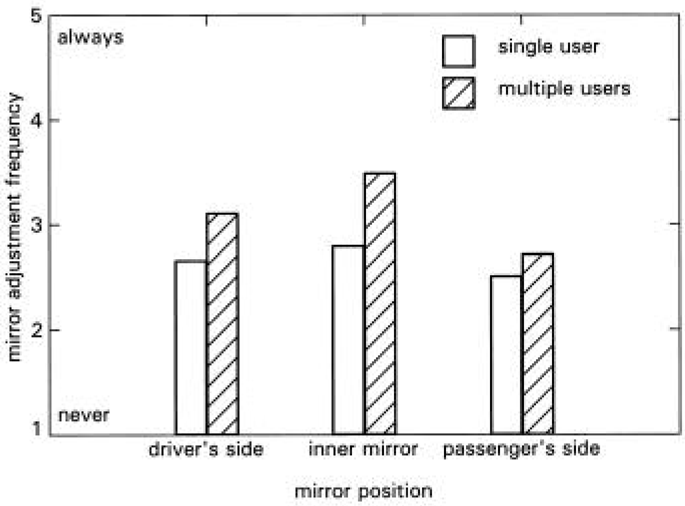

Figure 16 Adjustment frequency of the inner mirror, the driver's side mirror and the passenger's side mirror, for both drivers that only drive their car themselves and drivers that share their car with other drivers.

Concerning the strategy drivers use in aligning their driver's side mirror, respondents were asked if they align their mirror so they can see a part of their car as a reference or as far as possible outward to minimize blind spots. A log-linear analysis was applied with factors 'driver's side mirror type' and 'age group'. A main effect of age group was found [$\Pi^2=14.85$, $df=1$, $p<0.001$]. No effect of mirror type was found. 19% of the younger drivers indicated they turned their mirror outward as far as possible. 43% of the older respondents turned their mirror outward as far as possible. The respondents who indicated they had a different mirror alignment strategy than the two suggested strategies gave the following explanations (respondents driver's side mirror type and age group are indicated between parentheses):

- Such that the lane besides me is within the field of view (aspherical, young),
- Fitting together with inner mirror (spherical, young),
- Outer mirror is intentionally tilted upwards to avoid headlamp glare of overtaking cars (planar, old),
- In between, such that field view just skims along the side of the car (spherical, old),
- Optimize rear view (aspherical, young),
- None (planar, young),
- Blind spot mirror (aspherical, old),
- To the rear without seeing my own car (planar, young),
- So I can get a good view of the lane to the left (overtaking cars) (spherical, old),
- Such that my own car is just not visible anymore (aspherical, old),
- In between (spherical, old).

4.2.3 Mirror use

In order to investigate the way rearview mirrors are used for different sub-tasks, it was asked to give ratings for the information used for three types of checks which have to be made when overtaking or changing lanes to the left:

- Which information is used to check for vehicles *behind*
- Which information is used to check for vehicles *beside*
- Which information is used to *assess the distance and speed* of vehicles approaching from the rear

For each of these checking tasks, respondents were requested to give a rating on a five-point scale (from 1 'never' to 5 'always') of how often they use their rearview inner mirror, how often they use their driver's side mirror and how often they turn their head.

The ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group', 'checking task' (behind, beside, gap assessment) and 'information source' (turn head, driver's side mirror, inner mirror). Main effects were found for age group [$F(1,202)=6.64$, $p<0.05$], checking task [$F(2,404)=73,56$, $p<0.001$] and information source [$F(2,404)=65.77$, $p<0.001$]. No effect of mirror type was found [$F(2,202)=0.63$, n.s.]. Furthermore, interactions were found between checking task and information source [$F(4,808)=177,8$, $p<0.001$] and a third order interaction between mirror type, age group and information source [$F(4,404)=7.65$, $p<0.001$]. The average ratings showed that older respondents indicated slightly lower checking frequencies than younger respondents (average rating of 3.72 for older respondents and 3.97 for younger respondents). Of the three checking tasks the highest checking frequencies were indicated for checking for vehicles behind (average rating 4.26), followed by checking for vehicles beside (3.69) and the lowest ratings were given to gap assessment (3.59). The average ranking of the information sources was: highest ratings for driver's side mirror (average rating 4.28), second the inner mirror (3.87) and third turning one's head (3.39).

The interaction between checking task and information source is illustrated in Figure 17. The results confirmed the intuitive relative importance of the different information sources for each of the checking tasks: For checking behind, respondents turn their head less often than they check their mirrors. To check for vehicles beside, respondents use their inner mirror less often than they turn their head or check their driver's side mirror. In order to assess the distance and speed of vehicles coming from the rear the inner mirror is checked most frequently, followed by the driver's side mirror, while turning one's head got the lowest rating.

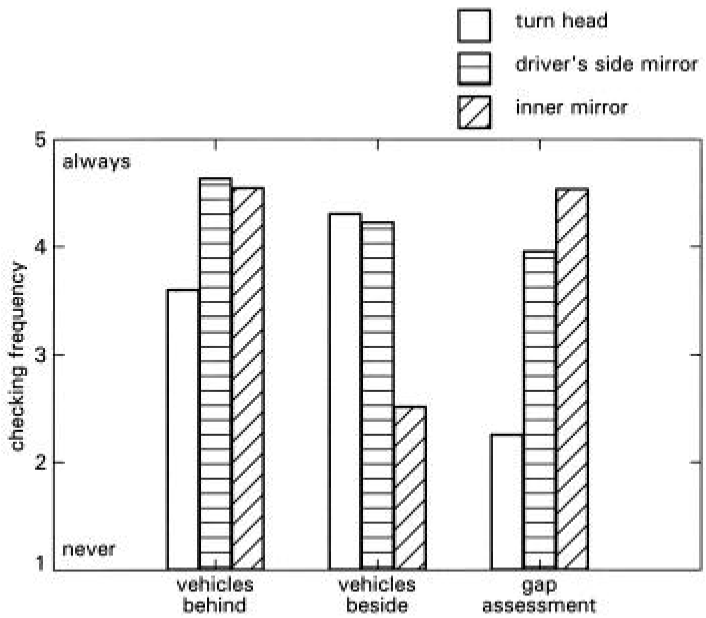

Figure 17 Checking frequency ratings per information source for three checking tasks.

Detailed analyses showed that the third order interaction between mirror type, age group and information source could be traced to 'turning one's head' where for all three checking tasks an interaction between mirror type and age group was found [F(2,2020=6.43, p<0.01]. Figure 18 illustrates this interaction. Younger drivers turn their head more often in case of planar mirrors when compared to non-planar mirrors. On the contrary, older drivers turn their head more often in case of aspherical mirrors when compared to planar and spherical convex mirrors. This later result is in line with the trend that was identified in the exploratory study.

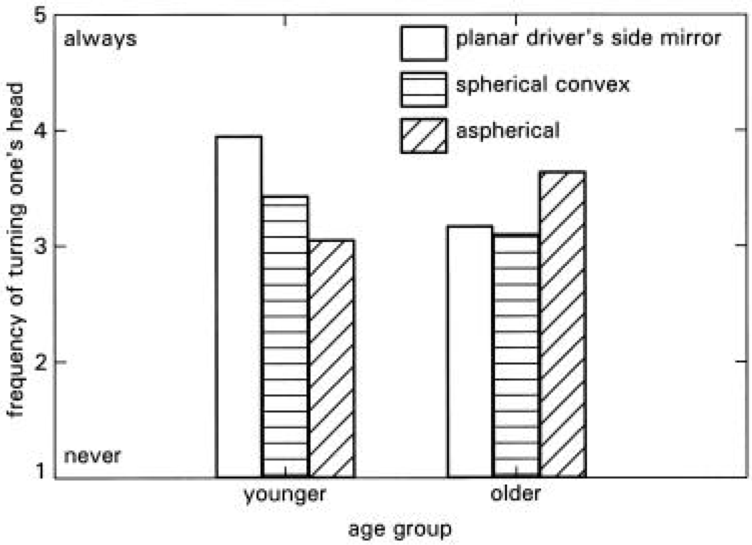

Figure 18 Interaction between mirror type and age group on the frequency of turning one's head.

Respondents were asked whether they were always sure it was safe when they overtook or changed lane to the left. Respondents gave separate ratings for daylight and darkness (rating from 1 'absolutely uncertain' to 5 'absolutely confident'). Ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group' and 'light condition' (daylight, dark). Only a marginally significant effect of light condition was found [F(1,199)=3.35, p<0.1). Respondents were slightly less confident in the dark (average confidence rating 4.4 for daylight and 4.3 for darkness). No effects of age group [F(1,199)=0.24, n.s.], nor mirror type [F(2,199)=0.79, n.s.] were found. In the exploratory study an interaction between mirror type and age group was found for the questions on perceived safety and confidence. This interaction did not reproduce in the present study.

Respondents gave ratings on whether or not they trusted the information they got from their inner mirror and their driver's side mirror. Again, separate ratings were given for daylight and for darkness. Ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group', 'mirror position' (inner mirror, driver's side mirror) and 'light condition' (daylight, darkness). Main effects were found of mirror position [F(1,196)=5.55, p<0.05] and light condition [F(1,196)=24.48, p<0.001]. Furthermore, an interaction between age group and mirror position was found [F(1,196)=5.69, p<0.05]. Similar to the results of the exploratory study, no main effects of mirror type or age group were found. In daylight, confidence was slightly higher than in the dark (4.23 versus 4.07). The average ratings showed that respondents were slightly more confident about the inner mirror (4.19) than the driver's side mirror (4.10). A detailed analysis of the interaction between age group and mirror position showed that this higher trust in the inner mirror is purely caused by a higher average rating of the younger respondents (4.28).

Concerning the assessment of vehicles approaching from the rear, respondents were asked to separately give a rating (scale from 1 'very badly' to 5 'very well') on the ability to estimate the distance and a rating on the ability to estimate the approach speed. The ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group' and 'estimation aspect' (distance, speed). Main effects were found for type of mirror [F(2,200)=3.30, p<0.05], age group [F(1,200)=5.89, p<0.05] and estimation aspect [F(1,200)=25.17, p<0.001]. Respondents indicated they were better able to estimate distance (average rating 4.16) than they were able to estimate approach speeds (3.97). Younger drivers gave somewhat higher ratings than older drivers (4.16 versus 3.97). Drivers with spherical convex mirrors on average gave a lower rating (3.93) than drivers with planar mirrors (4.10) and drivers with aspherical mirrors (4.17). In the exploratory study the averages suggested a (non significant) interaction between age and mirror type in the sense that estimation of distance and speed seemed to improve with mirror convexity for younger drivers, while it seemed to deteriorate for older drivers. The results of the large sample did not show such an interaction at all. The results did confirm that planar mirrors provide more adequate information for gap assessment than spherical convex mirrors, however, surprisingly, the subjective ratings of respondents with aspherical mirrors did not differ from the results for planar mirrors.

In order to see whether drivers compensate for their uncertainty by maintaining larger margins, respondents were asked whether they wait to change lanes until there are extra large gaps to other traffic because they do not trust the traffic information in the mirror. Separate ratings were given for daylight and darkness. The ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group' and 'light condition'. Main effects were found for age group [F(1,197)=20.81, p<0.001] and light condition [F(1,197)=28.40, p<0.001]. No main effect of mirror type was found [F(2,197)=0.01, n.s.]. However, there was a marginally significant interaction between mirror type and age group [F(2,197)=2.55, p<0.1]. Older respondents indicated they waited more often (average rating 3.33) for extra large gaps that younger respondents (2.56). Furthermore, respondents indicated that in the dark (3.06) they waited more often for larger gaps than during daytime (2.83). The interaction between mirror type and age group is illustrated in Figure 19. Older drivers with aspherical mirrors indicated they more often wait for larger gaps while younger drivers with aspherical mirrors indicated they less often wait for larger gaps. This interaction is consistent with the potential interaction between age and mirror type on the ability to estimate distance and speed identified in the exploratory study.

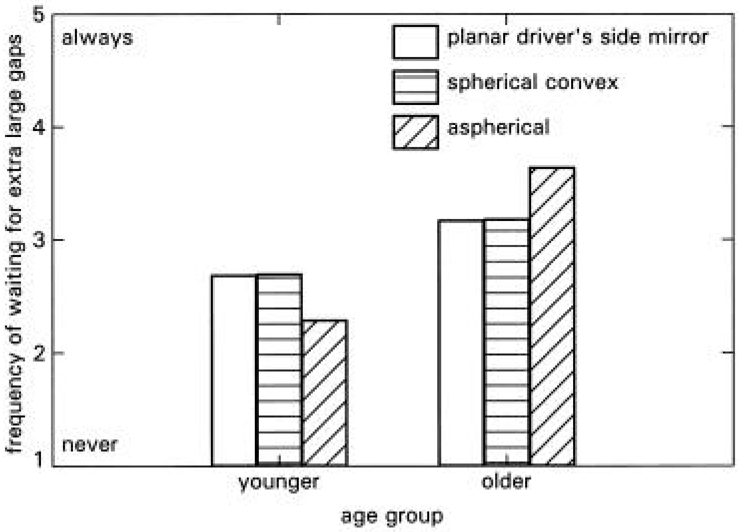

Figure 19 Frequency with which drivers wait for extra large gaps.

Similarly, in order to see whether drivers compensate for an inadequacy to estimate the approach speed of a car coming from the rear, respondents were asked whether they step on the accelerator and speed up when changing lanes. Separate ratings were given for daylight and darkness. The ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group' and 'light condition'. The only statistically significant effect was an interaction between age group and light condition [F(1,198)=5.05, P<0.05]. In the dark younger drivers step on the accelerator somewhat less often than during daylight (3.76 in daylight versus 3.70 in the dark), while older drivers seemed to do the opposite (3.71 in daylight versus 3.74 in the dark).

To investigate whether there is a relationship between the type of driver's side mirror and the occurrence of conflicts, respondents were asked whether they had any close calls during the last six months (or as long as they had their present car if this was shorter). Two types of conflicts were distinguished: First a rating (from 1 'never' to 5 'very often') was asked concerning how often it had occurred that when going to the left a car was in the blind spot and secondly a rating (from 1 'never' to 5 'very often') was asked for the frequency with which the respondent had seen a vehicle before moving to the left but made a wrong assessment of the safe gap when judging the closing speed.

The ratings were submitted to an ANOVA with factors 'driver's side mirror type', 'age group' and 'type of conflict' (blind spot, wrong assessment). Only a main effect of conflict type was found [F(1,200)=18.55, p<0.001]. The average frequency rating for blind spot conflicts was 1.47, while the average rating for the frequency of gap assessment conflicts was 1.27. Just like the exploratory study, no effects of age or mirror type were found.

4.2.4 Mirror awareness

In order to see whether drivers are aware of the way their mirror modifies the image, respondents were asked to chose between 'no modification', 'driver's side mirror minifies the image', 'driver's side mirror magnifies the image', 'driver's side mirror distorts the image', 'don't know'. A log-linear analysis was performed with design variables 'driver's side mirror type' and 'age group'. A marginally significant effect of mirror type was found [Π^2=15.26 (df=8) p<0.1]. Table 36 gives the distribution of the answers per mirror type. Of the respondents with a planar mirror, 35% thinks the image is modified while this is not the case. 46% of the respondents with a non-planar mirror think the image is not modified, while in fact the image is reduced. Of the respondents with aspherical mirrors, 15% say objects in the mirror are magnified instead of minified. Overall 43.2% of the respondents gave a correct answer.

Table 36 Respondents' opinion of the image modification characteristics of their driver's side mirror.

	Respondents' driver's side mirror type		
	planar	spherical convex	aspherical convex
no	61%	46%	46%
driver's side mirror minifies image	29%	36%	25%
driver's side mirror magnifies image	6%	2%	15%
driver's side mirror distorts image	0%	1%	4%
don't know	4%	15%	10%

In the next question, respondents were asked more directly what type of driver's side mirror they had. The multiple choice options were: 'planar', 'convex (constant convexity)', 'concave / hollow (constant concavity)', 'aspherical (varying curvature)' or 'don't know'. The options were illustrated with a schematic top view cross section of the relevant mirror types. Respondents were asked to not only indicate the type of mirror on their present car, but also the type of mirror on their previous car and if relevant the type of mirror on another car currently often driven by the respondent. A log-linear analysis was performed with design variables 'driver's side mirror type' and 'age group' and the respondents' answers as response variable. A main effect of mirror type was found [Π^2=33.03 (df=8) p<0.001]. No effect of age group was found. The distribution of the answers per mirror type is given in Table 37.

Table 37 Respondents' idea of the optical characteristics of their driver's side mirror.

	Respondents' driver's side mirror type		
	planar	spherical convex	aspherical convex
planar	77%	61%	45%
convex (constant convexity)	4%	7%	6%
concave / hollow (constant concavity)	3%	6%	4%
aspherical (varying curvature)	0%	3%	28%
don't know	16%	24%	17%

A second analysis was performed with the correctness of the answer as response variable. Again a main effect of mirror type was found [Π^2=81.71 (df=2) p<0.001]. Overall 35.1% of the respondents gave a correct answer, which is even less than the 45% of respondents of the exploratory study who accurately knew what type of mirror they had. 76.8% of the respondents with a planar mirror gave a correct answer. Only 6.7% of the respondents with a spherical convex mirror gave a correct answer and 27.7% of the respondents with an aspherical mirror gave a correct answer. 61% of the respondents with a spherical mirror thought their mirror was planar, while 45% of the respondents with an aspherical mirror thought their mirror was planar.

In view of the low proportion of correct answers and the fact that the mirror type of respondents' previous and other cars could not be determined, the responses concerning the previous and other cars were not further analyzed, nor were these responses taken into account in the analysis of other questions. It would have been interesting to analyze the time needed to get used to a certain type of mirror taking into account the type of mirror on the previous car.

The question was put how long it had taken to get used to respondents' present car's driver's side mirror after they first drove this vehicle. Respondents could chose from 8 options: 'no time needed to get used to present mirrors', 'about one day', 'about one week', 'about one month', 'about half a year', 'more than one year', 'other,...'. A log-linear analysis was performed with design variables 'driver's side mirror type' and 'age group' and the time period as response variable. No effects of age group or mirror type were found. In Figure 20 the distribution of time periods for the three mirror types is illustrated. Although not significant, the distributions suggest that mirror convexity and asphericality cause a shift to longer time periods needed to get used to mirrors.

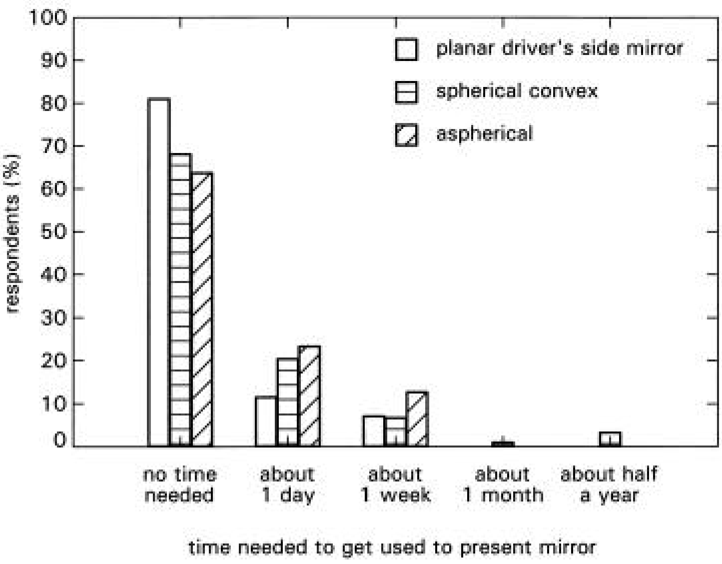

Figure 20 Time needed to get used to present mirror type.

Respondents gave an overall rating of how comfortable they felt using the driver's side mirror on their present car. An ANOVA of the comfort ratings with factors 'driver's side mirror type' and 'age group' did not show any effects. The overall average was 2.1, which was close to 'comfortable'.

A further rating (from 1 'very acceptable' to 6 'very uncomfortable') was given for the headlight glare respondents experienced at night in the driver's side mirror. An ANOVA showed a main effect of mirror type [$F(2,195)=6.35$, $p<0.01$]. Respondents with planar mirrors gave an average rating of 3.0 ('marginally acceptable'), respondents with spherical convex mirrors on average gave a rating of 2.4 (between 'marginally acceptable' and 'acceptable') and respondents with aspherical mirrors gave an average rating of 2.2 (close to 'acceptable'). A post hoc comparison showed that the discomfort glare rating for planar mirrors was significantly higher than the ratings for non-planar mirrors. The difference between spherical convex mirrors and aspherical mirrors was not significant.

Respondents were asked what kind of driver's side mirror they would prefer if they could chose. Four options were given: 'planar', 'convex; curved with constant radius', 'aspherical; curved with varying radius' and 'don't care'. A log-linear analysis was performed with design variables 'driver's side mirror type' and 'age group' and the respondents' mirror preference as response variable. A main effect of mirror type [$\Pi^2=23.12$ (df=6) $p<0.001$] was found, while age group showed a marginally significant effect [$\Pi^2=7.16$ (df=3) $p<0.1$]. The distribution of the answers per mirror type is illustrated in the Figures 21 and 22. Figure 21 shows that about half the respondents with a planar mirror or spherical convex mirror said they would prefer a planar mirror. A planar mirror was preferred by 31% of the respondents with an aspherical mirror. The proportion of respondents that indicated a preference for non-planar mirrors was in general low, with the exception of the respondents which an aspherical mirror. Of this latter group 36% said they prefer an aspherical mirror. As can be seen from Figure 22 the difference between younger respondents and older respondents related mostly to the preferences for planar mirrors and aspherical mirrors. Of the younger respondents 43% said they would prefer a planar mirror, while 54% of the older drivers said they prefer a planar mirror. For aspherical mirrors the opposite was found: 21% of the younger respondents preferred an aspherical mirror (22.4% of the younger respondents in the sample had an aspherical mirror) and 8% of the older drivers preferred an aspherical mirror (23.9% of the older respondents in the sample had an aspherical mirror). Overall 30% of the respondents said they don't care about the type of mirror.

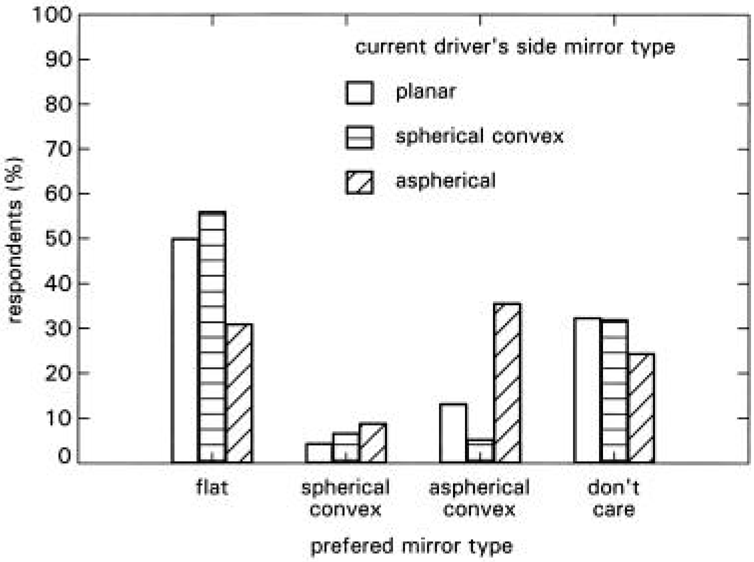

Figure 21 Drivers' preferred mirror type per current mirror type.

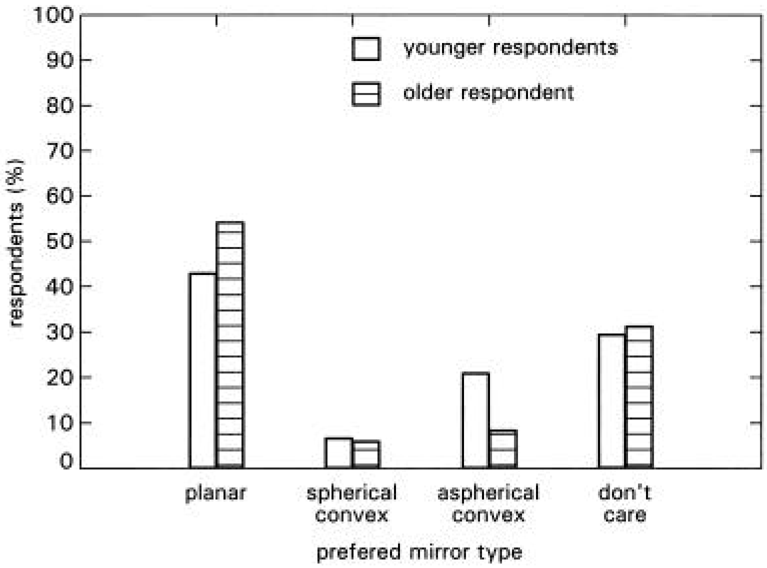

Figure 22 Drivers' preferred mirror type per age group.

4.2.5 Aspherical mirror strategies

Of the respondents possessing an aspherical mirror, 41 answered the questions concerning special strategies when using an aspherical mirror. Seven of those respondents (six younger and one older respondent) indicated they had a special strategy when using their aspherical mirror. Their explanations are given below:

- When a car is visible in the outer part of the mirror: don't go to the left (nevertheless always check!).
- Don't look, except at the start of overtaking.
- If a car is visible in the left quarter it is besides my car.
- Blind spot.
- In convex part actively look at blind spot.
- Ignore the so called blind spot part.
- Extra check when overtaking (beside me).

Ten of the respondents with an aspherical mirror indicated that they used the inner part and outer part of the mirror in different ways. Table 38 lists the notes given by the respondents.

In response to the question whether or not it is possible to move to the left when a car is visible in the outer part of the aspherical mirror, 10% answered they could.

Table 38 Respondents' notes concerning the differentiation between use of the inner and outer part of aspherical mirrors.

Usage inner part	Usage outer part
mostly	less
for checking	at the start of overtaking
assess distance + speed other traffic	only when changing to the left lane
normal use	blind spot
to be sure	to check
traffic coming from the rear	traffic beside own car
do use	don't use
before overtaking	just before overtaking
at larger distances	at the moment of overtaking
always	possibly subconsciously, but does not substitute a glance sideways

4.3 Discussion and conclusions revised questionnaire

Mirror adjustment

The results of the questions on mirror adjustment frequency showed that the inner mirror is adjusted most often, followed by the driver's side mirror, while the passenger's side mirror is adjusted least often. The questions did not provide a basis for a diagnosis of the reasons for this order. Three motives seem plausible: The shorter the distance between driver's eye-point the stronger the need for mirror adjustment in case of variations in eye-point. Another motive can be that the more a mirror is used (or the more important / essential the mirror information is) the stronger the need to accurately adjust the mirror. A third motive could be the required effort: The more effort required the less frequent a mirror will be adjusted. All three motives can to some extent explain the present effects: the inner mirror is closest by, thus most sensitive to eye-point variations and most easily adjusted; the passenger's side mirror is furthest away and thus least sensitive to eye-point variation and for most vehicles (without remote electrical adjustment mechanism) least easy to adjust. Only the order of mirror use frequency differed from the mirror adjustment frequency: The driver's side mirror was reported to be used somewhat more often than the inner mirror, while the inner mirror was adjusted more often.

Furthermore, the results of the questions on mirror adjustment frequency showed the more-or-less trivial effect that people who only drive their car themselves adjust their mirrors less often than drivers who share their car with other drivers. For respondents who are the only person driving their car it is likely that the reasons for adjusting the rearview mirrors are variability in body position (due to being tired or wearing thick clothes, etc.) or misalignment of the mirrors due to e.g. vibrations or someone bumping into the mirror in a parking lot. For people who share their car with other drivers the obvious additional cause is the difference between body postures of different drivers.

The urge to adjust a mirror given a change in mirror alignment or eye-point position might diminish with a large mirror field of view in case of non-planar mirrors. However, no effect of mirror type was found nor any interactions between mirror type and mirror position so the present results did not confirm this hypothesis.

Concerning the alignment strategy for the driver's side mirror, the results showed that twice as much older drivers (43%) turn their mirror outward as far as possible when compared to younger drivers (19%). It seems plausible that older driver's decrease of agility may be a motive to turn the mirror outward so that one has to turn one's head to a lesser extent. It could be expected that in case of planar mirrors the need to optimally use the limited field of view of this mirror type may increase the need to turn the mirror outward to reduce the blind spot. In case of non-planar mirrors, the large field of view might provide the possibility to align the mirror with the side of the car in order to have a reference and still only have a limited blind spot. However, due to the absence of any effects of mirror type on alignment strategy, no confirmation for this hypothesis was found.

Mirror use and compensation

The results on mirror checking frequency confirmed the intuitive relative importance of different information sources for different checking tasks. For checking in the rearward direction the mirrors are used most often, for checking besides their own vehicle drivers look less in the inner mirror than they turn their head and use the driver's side mirror. To assess the gap with respect to a vehicle approaching from the rear, the inner mirror is checked most frequently, followed by the driver's side mirror, while turning one's head got the lowest ratings.

A detailed analysis of the frequency of turning one's head showed that younger drivers turn their head less often in case of non-planar mirrors when compared to planar mirrors. These results confirmed the hypothesis that with increasing field of view, provided by non-planar mirrors, the frequency with which drivers need to turn their head diminishes. On the contrary, for older drivers there was no difference between planar and spherical convex mirrors, while respondents with aspherical mirrors indicated a higher frequency for turning their head than respondents with planar or spherical mirrors. This could indicate that older drivers do experience problems focusing the aspherical part or interpreting the image.

The hypothesis that due to the image size reduction of convex mirrors, gap assessment requires more frequent checking of the planar inner mirror was not confirmed. Although the ratings for the gap assessment task showed that the inner mirror is checked more frequently than the driver's side mirror, there was no additional effect of mirror type. Similarly, the results on the question whether or not respondents trust their mirrors showed that (especially younger) drivers are more confident about the inner mirror than the driver's side mirror, regardless of the type of driver's side mirror. It has to be noted that drivers' ratings will mainly reflect their opinion of which information sources should be checked for the different tasks and the checking frequency ratings may differ from the actual glance frequency.

There was however an effect that does confirm the influence of image reduction on gap assessment. In the results of the question on how well the respondents were able to assess the distance and speed of vehicles coming from the rear, drivers with spherical convex driver's side mirrors did indeed give significantly lower ratings than drivers with planar mirrors. The more or less surprising finding that the ratings of drivers with aspherical mirrors did not differ from the ratings for planar mirrors could be explained by the fact that for the majority of the aspherical mirrors the spherical part has a larger radius of curvature (2000 mm) than the majority of spherical mirrors (1400 mm) (de Vos, in preparation). Overall, respondents indicated they were better able to assess distances than speed differences, and younger drivers gave higher ratings about their ability of assess distance and speed than older drivers, but there were no interactions of these factors with mirror type.

The effects of light conditions were consistent throughout the various questions: In the dark drivers are less sure it is safe when overtaking or changing lanes, confidence is somewhat less and drivers compensate for these limitations in the dark by waiting more often for larger gaps. No interactions between mirror type and ambient light conditions were found.

The exploratory study suggested that there might be a relationship between mirror type and the reported involvement in blind spot related conflicts. However, the present results showed no effects of mirror type on either blind spot conflicts or close calls due to gap misjudgments.

Mirror awareness and preferences

Just like the exploratory study, the present results showed that drivers often do not have a correct idea about the optical effects of their mirror. One third of the drivers with a planar mirror thought their mirror modifies the image (most of them think the image is minified). More worrying was the result that almost half the drivers with non-planar mirrors thought their mirror does not modify the image, while in fact the image is minified. Overall, 43% of the respondents correctly knew the basic optical effects of their mirror while 35% correctly knew what optical type of driver's side mirror they had.

Although the distributions of the time it had taken respondents to get used to their driver's side mirror suggest that this period increases with increasing convexity, no significant effect was found. Comfort ratings concerning the use of the driver's side mirror did not show any effects of mirror type either. A preference for planar mirrors was stated by half the respondents with spherical mirrors and one third of the respondents with aspherical mirrors. In general, only a small proportion indicated a preference for non-planar mirrors. Drivers with aspherical mirrors were an exception to this general finding: about one third of them said they would prefer an aspherical mirror if they could chose. Overall, one third of the respondents did not have a preference for a specific type of mirror.

Concerning the item of headlight glare experienced at night in the driver's side mirror, drivers seemed to be less bothered by the headlight glare in non-planar mirrors than in planar mirrors. Whether a non-planar mirror is spherical or aspherical did not seem to make any further difference.

Strategies for aspherical mirrors

Of the drivers with aspherical mirrors, less than one fifth indicated they had a special strategy when using this mirror, while a quarter indicated that they used the spherical inner part and the aspherical outer part in different ways. Most comments suggested a role of the aspherical part for a final check before moving to the left and a check of the otherwise blind spot. Even a few responses indicated that the aspherical part is ignored. Ninety percent of the respondents with aspherical mirrors stated they can not move to the left when a vehicle is visible in the aspherical part of the driver's side mirror.

Summary of driver's side mirror type effects

In summary, the following driver's side mirror type related effects were found:

- Mirror type has no effects on mirror adjustment frequency and strategies.
- Younger drivers with non-planar driver's side mirrors turn their head less often than younger drivers with planar mirrors. Older drivers with aspherical mirrors turn their head more often when compared to older drivers with planar or spherical mirrors.
- Drivers with aspherical or planar mirrors think they are better able to assess gaps than drivers with spherical convex mirrors think they do.
- Less than half the drivers correctly knows the optical effects of their driver's side mirror and just about one third knows what optical type of mirror they have.
- Drivers with non-planar mirrors experience less headlight glare in their driver's side mirror than drivers with planar mirrors.

In general, it should be realized that there are limitations to the information gathered by means of questionnaires. For example, typically, answers are based on recent events and experiences. In addition, people are not always aware of the strategies they use and behaviors they display. People may be biased to give socially desirable answers. Finally people may give those answers they were taught (e.g. I always look over my shoulder when passing as learned in driving school, while in fact they never do). Even with these limitations, questionnaires give a first impression of the problems and peculiarities which then can be tested in a controlled field study (in our case Phase 2, see Chapter 5).

5 FIELD EXPERIMENT (Phase 2)

The second phase of the project consisted of an experimental part in which it was investigated whether the type of mirror has effects on gap acceptance, on the detection of vehicles at close range besides and behind the driver and on visual sampling behavior. In this study the effects of experience a driver has with a given certain type of mirror are analyzed as well as the effects of drivers age.

5.1 Method

5.1.1 Tasks and conditions

The field experiment consisted of two tasks investigating two aspects of the use of rearview mirrors. First, it was investigated how the assessment of a vehicle coming from behind is affected by different mirror types and secondly the detection of vehicles at close range in the adjacent lane was investigated. Subjects drove an instrumented mini van (Dodge Ram Van). During each trial first another car (Opel Vectra) approached the instrumented vehicle from behind in the left lane and the subjects were asked to indicate the last moment they thought it was safe to move into the adjacent lane in front of the car coming from behind. The other car approached with either a speed of 50 km/h or 80 km/h. After the subject indicated the 'last safe gap', the sideward field of view including the driver’s side rearview mirror was temporarily blocked by a curtain while the other car moved to various positions at close range of the subject’s vehicle and proceeded at the same speed. After the curtain was dropped, the subjects had to indicate whether there was another vehicle in the adjacent lane or not. Moreover, in case subjects detected another car, they had to indicate whether the other car was behind the subject’s car and they could still move into the other lane, or the two vehicles overlapped so it was not possible to move to the left. Five different positions of the second car were included: out of view, in the adjacent lane just behind the subject’s vehicle, just overlap with the subject’s vehicle, in the blind spot of the planar mirror (the blind spot of the non-planar mirrors was too small to accommodate a passenger car in the adjacent lane), in the direct field of view. The position just behind the subjects car and the position just overlapping the subject’s car were included to test whether or not it is more difficult to discern these conditions in case of non-planar mirrors.

In order to prevent the subjects from constantly looking at the driver’s side mirror, a secondary task was given. Every 50 m a circle with an opening on one side was painted on the road, just outside the edge line. The circles had the opening on either the top, bottom, left or right side. The sequence had a random order. Subjects were asked to verbally indicate on which side the opening of the circle was, top, bottom, left or right. The driving speed of 30 km/h together with the spacing of 50 m between each marker resulted that the subjects passed a marker every 6 seconds. The distance between the markers was such that when a marker was passed the next marker could just be located, however the opening could not be recognized yet. The experimenter made sure that the subjects paid adequate attention to the secondary task (verbal feedback was given if markers were skipped or incorrect responses were given). The performance on the secondary task was not registered.

An experimenter took care of the co-ordination of the experiment and a technician in the back supervised the equipment and took care of the data storage. The subject’s vehicle could be equipped with four types of driver's side rearview mirrors which were mounted on interchangeable panels. The mirror types were chosen based on the results of the inventory of Mirror characteristics (de Vos, in preparation a):

Mirror type I:	Planar mirror,
Mirror type II:	Spherical convex mirror with a radius of curvature of 1400 mm (most common radius for spherical mirrors driver’s side mirrors),

Mirror type III:	Aspherical convex mirror with a radius of curvature of the spherical part of 1400 mm (expected to become the most common type of aspherical mirror in the future),
Mirror type IV:	Aspherical convex mirror with a radius of curvature of the spherical part of 2000 mm (at present the most common type of aspherical mirror).

By comparing mirrors II and III, the differences between spherical and aspherical mirrors can be determined, without differences in radius of curvature as confounding factor. For the effects of being used to an aspherical mirror, the experimental mirror type IV should be considered, because up to the time of the experiment almost all aspherical mirrors had a radius of curvature of about 2000 mm.

The width of the mirror surfaces was chosen based on the results of the inventory of mirror characteristics (Chapter 2). The average ratio of the width of the driver's side mirror and the distance from the driver's eye point to the mirror was 0.2. For the instrumented vehicle the distance from the driver's eye point to the driver's side mirror was 0.9 m resulting a mirror width of 0.18 m. Identical masks were mounted on top of all four mirror surfaces (see Figure 23). The largest width of the resulting mirror area was 180 mm and the largest height was 125 mm. The oval contour of the available mirror surface was characteristic for a passenger car outside mirror. The aspherical mirrors consisted of a spherical section on the right side and a section with decreasing radius of curvature to the left. The largest width of the spherical section was 135 mm (75% of the total largest width), and the largest width of the aspherical section was 45 mm (25% of the total largest width). A vertical dashed line was etched at the transition between the spherical section and the aspherical section.

Figure 23 Mirror panel (aspherical mirror) mounted on the instrumented vehicle.

Before each session the driver's side mirror was aligned in such a way that the subject could just see the edge of the instrumented vehicle. During the experiment, the rearview inner mirror was turned away towards the experimenter in order to make sure that the subjects made their estimates on the basis of the image presented by the driver's side mirror only. Although one may argue that this is unlike natural driving, it should be realized that the sole use of the outside rearview mirror could be considered to be a 'worst case' scenario.

Subject's responses were registered by means of three buttons which were mounted on a box near the indicator (from top to bottom: a red, a green, and a white button). Furthermore, the vehicle was equipped with two video cameras. One camera was aimed at the subject's face in order to register glance behavior. The second camera was positioned behind the rear window and aimed at the car coming from behind. From this video image the distance between the two vehicles was determined.

The experiment took place during clear weather on a straight track with a length of 1.1 km (see Figure 24). This dead end dike-road in the reclaimed land 'Flevoland' consisted of two lanes and emergency lanes on both sides. For the experiment the road was closed to other traffic.

Figure 24 The experimental setting at the 'IJmeerdijk': in the left lane the 'target car', in the right lane the instrumented vehicle. In the bottom righthand corner one of the C shaped markers for the secondary task.

In summary the experiment consisted of the following conditions:

Own mirror:	planar, spherical, aspherical
Age:	young, old
Experimental mirror:	planar, spherical, aspherical 1400, aspherical 2000
Approach speed ('last safe gap' task):	50 km/h, 80 km/h
Position of the second car ('vehicle detection' task):	out of view, just behind subject's vehicle, just overlap with subject's vehicle, in the blind spot of the planar mirror, in the direct field of view.

The variables 'own mirror' and 'age' were all between subjects, while all the other variables were within subjects. To ensure stable data, conditions were repeated. The 'last safe gap' conditions were repeated six times resulting in 4 (mirror type) x 2 (speed) x 6 (replica) = 48 trials per subject. The 'vehicle detection' conditions were repeated 2 times, with exception of the out of view condition, which occurred twice as often as the other conditions. This again resulted in 4 (mirror type) x 6 (position other car) x 2 (replication) = 48 trials per subject.

5.1.2 Procedure

During one day two subjects participated in parallel. After arrival at the TNO Human Factors Research Institute in Soesterberg, subjects read the written instruction (Appendix D) and completed the informed consent agreement (Appendix E). The mirror characteristics of the subject's own vehicle were measured. The characteristics of the instrumented vehicle were explained to the subjects. Subjects drove the instrumented vehicle to the experimental location (a distance of 50 km, that took about 45 minutes of driving). Half way through the journey the subjects changed places, so both subjects had the opportunity to get used to the vehicle (during the trip the instrumented vehicle was equipped with the same type of mirror as subject's own vehicle).

At the start of a trial, subjects accelerated and the cruise control was switched on at a set speed of 30 km/h. After about 30 seconds the computer of the instrumented vehicle sent a radio message to the second car (Opel Vectra) giving an instruction to the driver of this car to accelerate to a certain speed (either 50 km/h or 80 km/h). The timing was chosen in such a way that the second car reached the prescribed speed in steady state while being at least 200 meters behind the subject's vehicle. The task of the subjects was to indicate until which moment they deemed it safe to move into the adjacent lane in front of the vehicle approaching from behind. For this purpose subjects were instructed to press the green button from the start of the trial, as if they turned on their indicator. The subjects indicated the 'last safe gap' by changing from the green button to the red button, as if they turned off their indicator.

At the moment the subject indicated the 'last safe gap' the procedure for the 'vehicle detection' task started. The experimenter pulled up the curtain blocking the direct field of view through the left window and in the driver's side mirror (Figure 25). The computer of the instrumented car sent a radio message to the second car instructing the driver to move to one of the five positions. As soon as the second car reached the planned position, the driver pushed a button that triggered the computer of the instrumented car to drop the curtain (Figure 26). Subjects gave a response by pressing one of the three buttons:

White button =	No other car in the adjacent lane,
Green button =	Other car present in the adjacent lane, however no overlap, so still possible to move into the other lane, or
Red button =	Other car present in the adjacent lane. Overlap between the two cars, so no possibility to move into the other lane.

For the detection task subjects could look in the driver's side mirror and turn their head. They were encouraged to act just like they would normally do to check whether they could move to the left. There was no time limit for the detection task, however, in the written instruction subjects were encouraged to give a swift and accurate response.

After completion of the vehicle detection task, the two cars drove to the end of the track, turned around and started the next trial.

Figure 25 Curtain closed to block the field of view through the left window and in the driver's side mirror.

Figure 26 Curtain open.

Sessions
All subjects drove four sessions, each lasting about half an hour. Subjects alternated after each session. One session consisted of one mirror condition. In order not to disturb the effect of being accustomed to a certain type of mirror, subjects always started with the mirror condition which corresponded to the type of mirror on their own car. The order of the mirror types with which the subjects were not familiar were counter balanced between subjects. Within a session, consisting of 12 trials, the two approach speed conditions occurred 6 times in random order. During a session each of the locations of the second car occurred twice in random order, with the exception of the condition with the second car out of view which occurred 4 times. Before the first session started subjects practiced on the task for 3 to 5 trials until they reached a sufficient level of skill in the experimental procedure.

Visual acuity measurements
After return at the TNO facilities in Soesterberg, subject's visual characteristics were measured:

- Standard Landolt-C acuity test (concerning the relationship between the Landolt-C acuity test and the Snellen test, Grimm et al. (1994) found that in order to obtain comparable visual acuity scores, the Snellen optotypes must be approximately 15% smaller than the diameter of the Landolt ring).
- Landolt-C acuity test via the four types of mirrors: the subjects were in the driver’s seat and looked at the Landolt-C chart via the driver's side mirror. The distance between the driver's eye-point and the driver's side mirror was approximately 1 meter. The Landolt-C chart was positioned at 4 meters behind the rearview mirror. So, for the planar mirror the distance between the virtual view point and the visual acuity chart was identical to the standard distance for the standard Landolt-C acuity test.
- The near focus distance was measured using a ruler along which a panel could be moved. On the panel a sheet was fixed with a text printed in courier 12 point front. Subjects were instructed to hold one end of the ruler against their nose and to move the panel along the ruler towards their nose to such a distance that they still could just focus on the text. The distance between the panel and the nose-tip was then read from the ruler.

All measurements took place in daylight.

5.1.3 Subjects

In total 36 paid subjects participated in the experiment, divided into three groups of twelve subjects. The first group was accustomed to a planar driver's side mirror on their own car, the second group had a spherical convex mirror on their own car and the third group consisted of drivers with an aspherical driver's side mirror. For each group six subjects were younger (25-45) and six subjects were older (60-75). The characteristics of the subjects are summarized in Table 39. Subjects were found through the TNO database in which people are registered who are prepared to participate in experiments in the instrumented vehicle or in the driving simulator (usually this database is filled by means of advertisements in a local newspapers). The date of birth of the people in this database is known, so potential subjects could be selected based on age. However, the type of mirror on their own car is not registered. When potential subjects were called to make an appointment, they were asked to have a look at their driver's side mirror in order to classify them in one of the three 'own mirror' groups. An exception was formed by a small group in the database: added as last page of the questionnaires (see Chapters 3 and 4) was the standard form with which people can express their interest to be added to the database. For the people that completed the form attached to the questionnaire, the mirror characteristics were known and those people could be approached more specifically to fill a certain age x own mirror type cell.

Table 39 Characteristics of the subjects (Std dev = Standard deviation; ROC = Radius of curvature).

Own mirror type	Age group	Age (years)				ROC driver's side mirror (mm)	Visual acuity		Near focus distance (cm)
		Average	Std dev	Min	Max		Average	Std dev	
Planar	Young	36.8	4.0	31	41	-	1.34	0.42	9.6
	Old	68.8	5.0	61	74	-	0.94	0.18	13.5
Spherical convex	Young	31.8	5.3	27	42	1728	1.50	0.27	8.9
	Old	68.8	3.1	64	72	1619	0.95	0.38	10.5
Aspherical convex	Young	31.5	3.9	26	36	2023	1.38	0.51	8.3
	Old	61.8	2.6	60	67	2049	1.18	0.24	11.5

An analysis of variance on the subjects' age not only showed a significant difference between the age groups [$F(1,30)=578.5$, $p<0.001$], but also a main effect of own mirror type was found [$F(2,30)=6.77$, $p<0.01$]. A post hoc analysis showed that the subjects with an aspherical mirror on their own car were somewhat younger than the subjects with a planar mirror on their own car ($p<0.01$). Assuming that there might be some correlation between driver's age and vehicle age, this difference may be explained by the fact that aspherical mirrors are mainly installed on recent cars, while planar mirrors are found on older cars (de Vos, in preparation a).

An analysis of variance performed on the subjects' visual acuity only showed an effect of age group [$F(1,30)=10.8$, $p<0.01$] (no effect of own mirror type [$F(2,30)=0.46$, n.s.]), and similarly for the near focus distance a marginally significant effect of age group was found [$F(1,30)=3.97$, $p<0.1$] (again no effect of own mirror type [$F(2,30)=0.65$, n.s.]).

During the preparation of the experiment it was suggested that the near focus distance, which increases with age, may play a role in the effects of mirror curvature. In case of a planar mirror, the distance between the driver's eye-point and the virtual image is comparable to the distance to the object that is observed, however in case of non-planar mirrors the distance to the virtual image is much shorter (Koutstaal, 1967). In case the distance to the virtual image would be shorter than a subject's near focus distance, the subject would not be able to focus on the image. Although there was a marginally significant difference between the near focus distance for the older subjects and the younger subjects [F(2,30)=3.96, p<0.1], the near focus distances in the daylight conditions of the experiment (in low ambient light conditions the near focus distance for older people may increase considerably) were so short that it is not likely to be a cause for any problems with non-planar mirrors.

It can be noted that the relative position of driver's side mirror of the instrumented mini van with respect to the driver's eye point was very similar to the relative position in a normal passenger car, both with respect to the distance from the drivers eye point to the mirror surface (0.9 m for the instrumented vehicle and on average 0.85 m for the nine recent cars that were considered in section 2.3) and the downward angle at which the mirror is oriented with respect to the eye point (about 20 degrees for a driver of 1.87 m tall). In an absolute sense, for the instrumented vehicle the height of the center of the driver's side mirror was 1.14 m, which is about 0.2 m higher than for a normal passenger car.

5.1.4 Analysis

The video recordings were analyzed off-line in order to derive the last safe gap data and in order to analyze glance behavior. The video analysis unit automatically moved the video tape forward until the point was reached where the subject had indicated the last safe gap (during the experiment this point was marked in the user bit code of the video recordings). The video analyst then marked the outer contours of both front wheels of the second car. Based on a calibration, the computer then used the number of pixels between the two points to calculate the distance between the two cars.

The glance behavior for the last safe gap task was analyzed for the last 10 seconds preceding the last safe gap response. The analyst indicated the glance direction by pressing three buttons corresponding to the subject looking ahead, looking at the driver's side mirror and looking over one's shoulder. The video tape was played at half the normal speed. In order to analyze the glance behavior during the vehicle detection task the video tape was started at the moment the curtain was dropped and stopped at the moment the subject gave a response.

5.2 Results

5.2.1 Visual acuity via the experimental mirrors

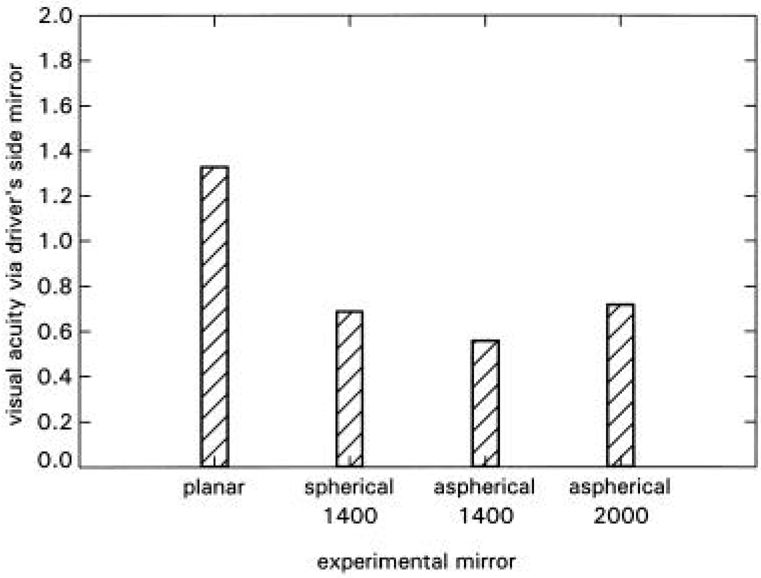

Figure 27 Average visual acuity measured when looking at the Landolt-C chart via the four experimental mirrors.

The average visual acuity (averaged over all 36 subjects) measured when looking at the Landolt-C chart via the four experimental mirrors showed a main effect of mirror type [$F(3,90)=4.71$, $p<0.01$]. The effective visual acuity is reduced in case of non-planar mirrors, see Figure 27. A post hoc analysis shows that the differences between the planar mirror (visual acuity 1.33) and the three non-planar mirrors (visual acuities via the spherical convex mirror, the aspherical mirror with radius of 1400 mm, and the aspherical 2000 mm mirror were 0.69, 0.56 and 0.72, respectively) are significant ($p<0.05$), while the differences among the non-planar mirrors are not.

5.2.2 Gap acceptance

5.2.2.1 Last safe gap

Distance gap

The 'last safe distance gaps' were submitted to an analysis of variance with factors 'own mirror' (planar, spherical, aspherical), 'age' (young, old), 'experimental mirror' (planar, spherical, aspherical 1400, aspherical 2000), 'approach speed' (50, 80 km/h) and 'replication' (1..6). Main effects were found for the factors 'experimental mirror' [$F(3,90)=8.81$, $p<0.001$] and 'approach speed' [$F(1,30)=104.64$, $p<0.001$]. No main effect was found for 'own mirror' [$F(2,30)=0.20$, n.s.] and 'age' [$F(1,30)=0.10$, n.s.]. 'Replication' showed a marginally significant effect [$F(5,150)=2.11$, $p<0.1$]. Second order interactions were found between 'own mirror' and 'experimental mirror' [$F(6,90)=2.59$, $p<0.05$] as well as between 'age' and 'approach speed' [$F(1,30)=9.89$, $p<0.01$]. A post-hoc analysis of the effect of experimental mirror showed a significant difference in distance gap between the planar experimental mirror and the three non-planar mirrors ($p<0.001$ for the spherical mirror and the aspherical 1400 mirror; $p<0.05$ for the aspherical 2000 mirror). The average distance gaps for the four experimental mirror conditions are illustrated in Figure 28. The graph suggests that the average distance gap for the 2000 mm aspherical mirror is just inbetween the planar mirror and the two mirrors with a radius of 1400 mm, however the differences between the 2000 mm and 1400 mm mirrors are not significant.

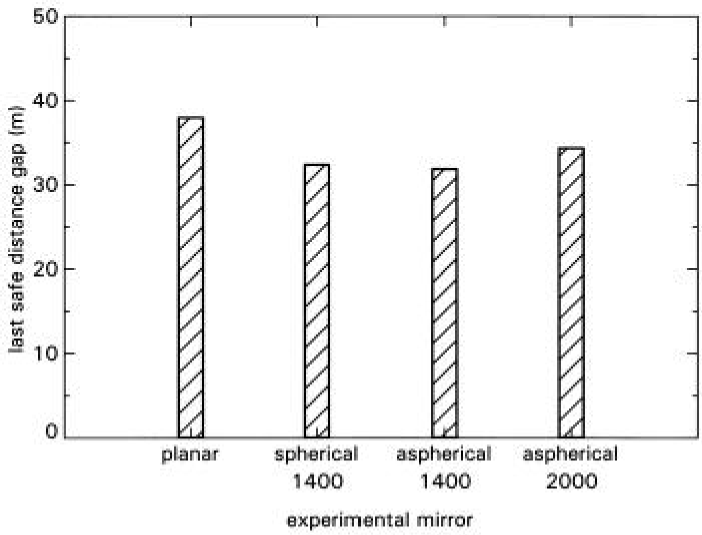

Figure 28 Average 'last safe distance gap' for the four experimental mirror conditions.

The overall averaged distance gaps for the two approach speed conditions were 28.4 m in case of an approach speed of 50 km/h and 40.0 m in case of an approach speed of 80 km/h.

The marginal effect of replication suggests a reduction of the distance gap when conditions are repeated. Averaged over speed and mirror conditions the distance gap for first time conditions occurred was 34.8 m, while for replication 5 the lowest average was reached at 33.4 m. However, a post-hoc analysis showed no significant differences between any pair of individual replications.

The most remarkable finding of the post-hoc analysis of the interaction between ‘own mirror’ and ‘experimental mirror’ is that for the spherical experimental mirror, subjects with a spherical mirror on their own car selected significantly larger distance gaps compared to subjects who are used to planar or aspherical mirrors ($p<0.05$ and $p<0.01$). Furthermore, drivers with an aspherical mirror on their own car selected larger distance gaps when they drove with a planar experimental mirror, than with a spherical experimental mirror ($p<0.01$). This interaction is illustrated in Figure 29.

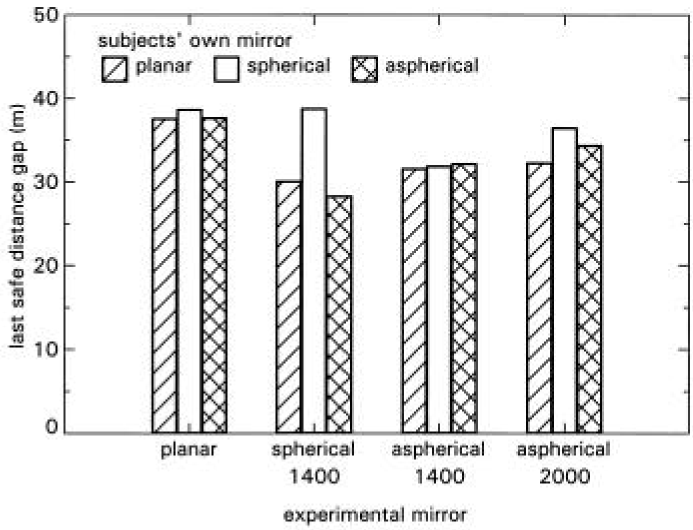

Figure 29 Average ‘last safe distance gap’ for the four experimental mirror conditions, broken down according to ‘own mirror’ group.

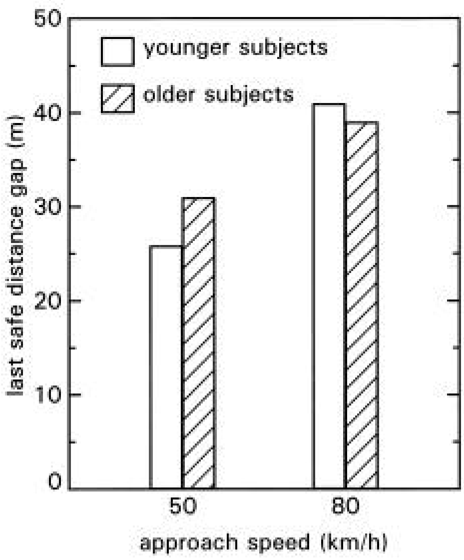

Figure 30 Average ‘last safe distance gap’ for the two speed conditions and the two age groups.

An analysis of the interaction between ‘age’ and ‘approach speed ‘ showed that at the low approach speed of 50 km/h older subjects maintained a larger distance gap than younger subjects (31.0 m versus

25.8 m) while at the higher approach speed of 80 km/h the average distance gap for the two age groups do not differ (older subjects 39.0 m and younger subjects 40.1 m) (see Figure 30). This result may indicate that older drivers try to maintain larger margins than younger drivers, in which they succeed only at low speed differences (= short distances).

Time gap

The ‘last safe time gaps’ (gap in meters divided by the speed difference) were submitted to an analysis of variance with factors ‘own mirror’ (planar, spherical, aspherical), ‘age’ (young, old), ‘experimental mirror’ (planar, spherical, aspherical 1400, aspherical 2000), ‘approach speed’ (50, 80 km/h) and ‘replication’ (1..6). Main effects were found for the factors ‘experimental mirror’ [$F(3,90)=7.76$, $p<0.001$], ‘approach speed’ [$F(1,90)=54.7$, $p<0.001$] and ‘replication’ [$F(1,150)=2.3$, $p<0.05$]. No significant main effects were found for the factors ‘own mirror’ [$F(2,30)=0.19$, n.s.] and ‘ age’ [$F(1,30)=0.38$, n.s.]. An interaction was found between factors ‘approach speed’ and ‘replication’ [$F(5,150)=3.88$, $p<0.01$]. Marginally significant interactions were found between factors ‘own mirror’ and ‘experimental mirror’ [$F(6,90)=2.17$, $p<0.1$] and between factors ‘age’ and ‘approach speed’ [$F(1,30)=3.17$, $p<0.1$].

A post-hoc analysis of the effect of experimental mirror showed a significant difference in time gap between the planar experimental mirror and the three non-planar mirrors ($p<0.01$ for the spherical mirror, $p<0.001$ for the aspherical 1400 mirror, and $p<0.05$ for the aspherical 2000 mirror). The average time gaps for the four experimental mirror conditions are illustrated in Figure 31. The graph suggests that the average distance gap for the 2000 mm aspherical mirror is just between the planar mirror and the two mirrors with a radius of 1400 mm, however the differences between the 2000 mm and 1400 mm mirrors are not significant.

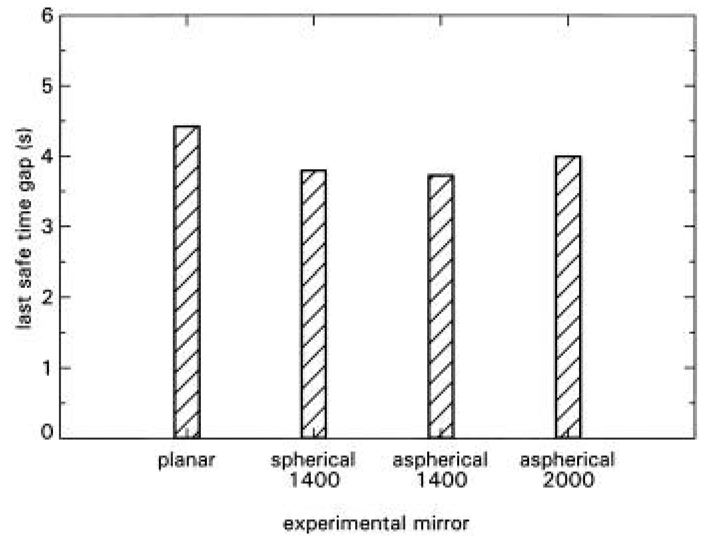

Figure 31 Average ‘last safe time gap’ for the four experimental mirror conditions.

Although the distance gap increased with increasing approach speed, the time gap decreased: the overall averaged time gaps were 5.1 s in case of an approach speed of 50 km/h and 2.9 s in case of an approach speed of 80 km/h.

The effect of replication shows a reduction of the time gap when conditions are repeated. Averaged over speed and mirror conditions the time gap for first time conditions occurred was 4.1 s, while for replication 5 the lowest average was reached at 3.9 s. A post-hoc analysis showed only a significant difference between replications 1 and 5 ($p<0.05$).

Similar to the analysis of the distance gap, a post-hoc analysis of the time gap interaction between 'own mirror' and 'experimental mirror' shows that for the spherical experimental mirror, subjects with a spherical mirror on their own car maintained significantly larger distance gaps compared to subjects who are used to planar or aspherical mirrors ($p<0.1$ and $p<0.01$, respectively). Furthermore, drivers with an aspherical mirror on their own car maintained larger time gaps when they drove with a planar experimental mirror, when compared to a spherical experimental mirror ($p<0.01$). This interaction is illustrated in Figure 32.

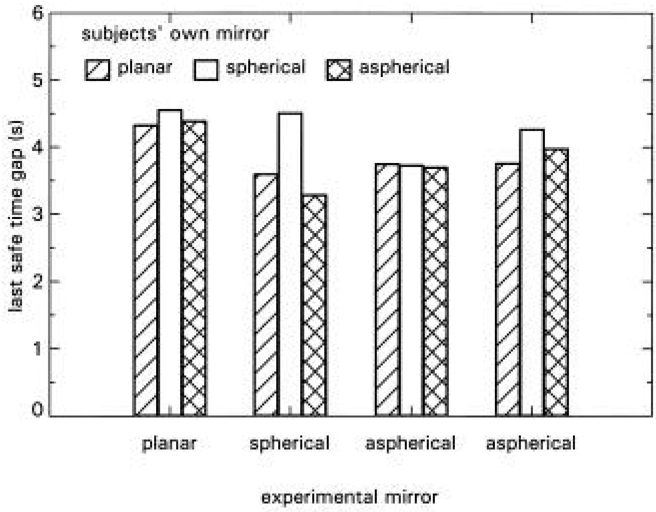

Figure 32 Average 'last safe time gap' for the four experimental mirror conditions, broken down according to 'own mirror' group.

A detailed analysis of the interaction between 'approach speed' and 'replication' shows that for the approach speed of 50 km/h the time gap for the first replication is somewhat larger than for replications 3 ($p<0.001$), 4 ($p<0.05$), 5 ($p<0.01$) and 6 ($p<0.01$): 5.4 s for replication 1 and 5.0 s for replications 3 till 6. For the higher approach speed no differences between replications were found.

An analysis of the marginally significant interaction between 'age' and 'approach speed ' suggests that at the low approach speed of 50 km/h older subjects maintained a larger time gap than younger subjects (5.6 s versus 4.6 s), similar to the distance gap. However, a post-hoc comparison showed that this time gap difference is not significant. At the higher approach speed of 80 km/h the average time gap for the two age groups do not differ (older subjects 2.8 s, younger subjects 2.9 s) (see Figure 33).

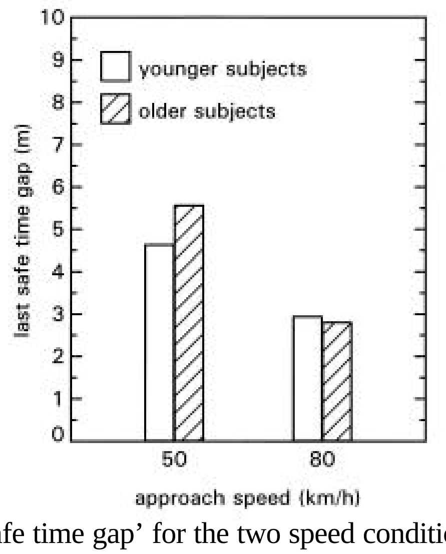

Figure 33 Average 'last safe time gap' for the two speed conditions and the two age groups.

5.2.2.2 Drivers' glance behavior

Dwell time

The drivers' dwell times in the direction of the driver's side rearview mirror were submitted to an analysis of variance with factors 'own mirror' (planar, spherical, aspherical), 'age' (young, old), 'experimental mirror' (planar, spherical, aspherical 1400, aspherical 2000), 'approach speed' (50, 80 km/h) and 'replication' (1..6). No main effects of any of these factors were found (own mirror [F(2,30)=0.40, not significant (n.s.)], age [F(1,30)=0.51, n.s.], experimental mirror [F(3,90)=0.99, n.s.], approach speed [F(1,30)=0.12, n.s.], replication [F(5,150)=1.06, n.s.]). Only a marginally significant interaction between age and approach speed was found [F(1,30)=3.14, p<0.1]. The average dwell time was 1646 ms. The interaction showed that at the 50 km/h approach speed, the average dwell times of younger and older subjects were almost the same (1710 ms and 1739 ms, respectively), while at the approach speed of 80 km/h the dwell times of younger subjects were longer, compared to older drivers: at 80 km/h approach speed the average dwell time for younger subjects was 1892 ms and the average dwell time for older subjects was 1616 ms (see Figure 34). Based on the gradual degradation of the visual system with age, the opposite would be expected, i.e. that older drivers would need longer dwell times to assess a gap in case of a higher approach speed and larger distance.

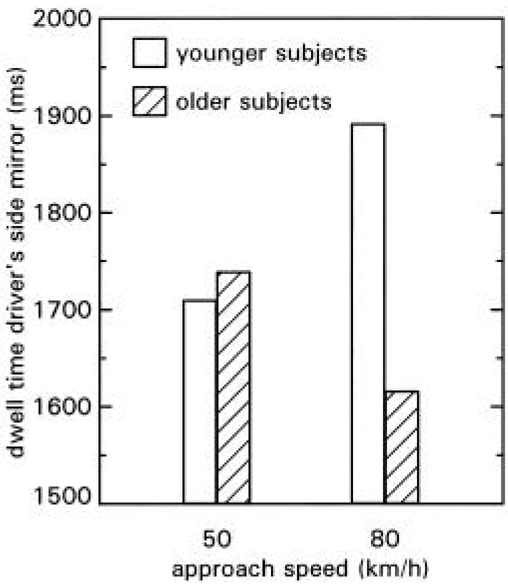

Figure 34 Average dwell times driver's side mirror: the interaction between approach speed and age.

Number of glances

The number of glances in the direction of the driver's side rearview mirror were submitted to an analysis of variance with factors 'own mirror' (planar, spherical, aspherical), 'age' (young, old), 'experimental mirror' (planar, spherical, aspherical 1400, aspherical 2000), 'approach speed' (50, 80 km/h) and 'replication' (1..6). A main effect of 'speed' was found [F(1,30)=80.31, p<0.001]. Marginally significant effects were found for the factors 'own mirror' [F(2,30)=3.19, p<0.1] and 'age' [F(1,30)=3.70, p<0.1]. The factor 'experimental mirror' showed no significant effect [F(3,90)=1.04, n.s.]. With respect to the factor 'own mirror', during the experiment, subjects with a spherical mirror on their own car sampled the rearview mirrors more often than subjects with a planar mirror on their own car, respectively 2.8 and 2.1 times. Subjects with an aspherical mirror on their own car sampled the rearview mirror 2.4 times which did not differ from the two other types of mirror. Furthermore older subjects sampled the rearview mirrors more often than younger subjects: 2.6 times versus 2.2 times on average. In the case where the overtaking car approached at 50 km/h, the rearview mirror was sampled more often than in the case where the approach speed was 80 km/h: 2.6 times versus 2.2 times.

5.2.3 Vehicle detection

5.2.3.1 Detection performance

Two aspects of the detection performance were analyzed: First, whether or not a vehicle in the adjacent lane was detected, and secondly, whether or not subjects made a proper assessment of the overlap/underlap between the car in the adjacent lane and the instrumented car driven by the subject.

Vehicle presence/absence

The detection faults (i.e. when subjects indicated that there wasn't a car in the adjacent lane, while in fact there was) were submitted to an analysis of variance with factors 'own mirror' (planar, spherical, aspherical), 'age' (young, old), 'experimental mirror' (planar, spherical, aspherical 1400, aspherical 2000), 'position of the second car' (just behind the subject's vehicle, just overlap with the subject's vehicle, in the planar mirror blind spot, in the direct field of view) and 'replication' (1..2). Main effects were found for the factors 'own mirror' [$F(2,30)=4.53$, $p<0.05$], 'experimental mirror' [$F(3,90)=54.4$, $p<0.001$], and 'position of the second car' [$F(3,90)=12.7$, $p<0.001$]. No significant main effects were found for the factors 'age' [$F(1,30)=0.59$, n.s.] and 'replication' [$F(1,30)=0.26$, n.s.]. Interactions were found between 'own mirror' and 'experimental mirror' [$F(6,90)=4.28$, $p<0.001$], between 'experimental mirror' and 'position' [$F(9,270)=12.1$, $p<0.001$ and (marginally significant) between 'age' and 'experimental mirror' [$F(3,90)=2.61$, $p<0.1$].

A post hoc analysis of the differences between 'own mirror' categories showed that the percentage of detection faults for subjects with a planar mirror on their own car was higher than for subjects with a spherical mirror on their own car, 17.2% versus 7.3% ($p<0.05$). The percentage of detection faults for subjects with an aspherical mirror on their own car was 10.9%, which did not significantly differ from the other two groups.

A post hoc analysis of the difference between the 'experimental mirror' categories showed that the percentage of detection faults for the planar experimental mirror (30.1%) was higher than for the three non-planar mirrors ($p<0.001$): 8.3% for the spherical mirror, 4.2% for the aspherical 1400 mm mirror and 3.8% for the aspherical 2000 mm mirror. No significant differences between the non-planar mirrors were found.

A detailed analysis of the differences between the percentages of detection faults for the four positions of the second car showed that the percentage for the position in the blind spot (22.9%) was higher than the percentages for the position just behind the subject's vehicle (8.3%) and the position in the direct field of view (1.7%) ($p<0.001$). Furthermore, the percentage of detection faults for the position in the direct field of view was lower than for the position where there was just an overlap between the two vehicles with the subjects vehicle (14.2%) ($p<0.01$).

A detailed analysis of the interaction between 'own mirror' and 'experimental mirror' showed that mainly subjects with a planar mirror on their own car had a higher percentage of detection faults for the planar experimental mirror when compared to the three non-planar experimental mirrors ($p<0.001$). Surprisingly, when using the planar experimental mirror, the subjects with a spherical mirror on their own car had a lower percentage of detection faults than drivers who use a planar mirror on their own car ($p<0.001$) (see Figure 35).

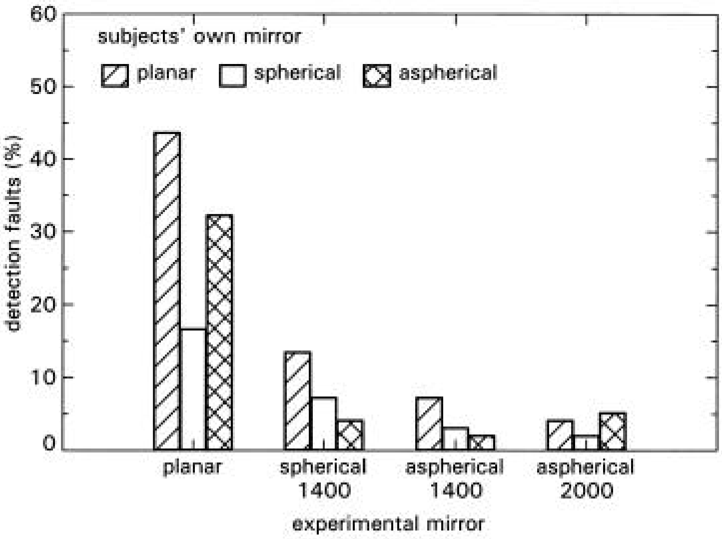

Figure 35 Detection faults for the four experimental mirror conditions, broken down according to 'own mirror' group.

The average percentages of detection faults for the interaction between ‘age’ and ‘experimental mirror’ suggest that older subjects made fewer mistakes than younger subjects when using the planar experimental mirror, while they made more mistakes using the non-planar mirrors (see Figure 36). However, none of these differences were statistically significant.

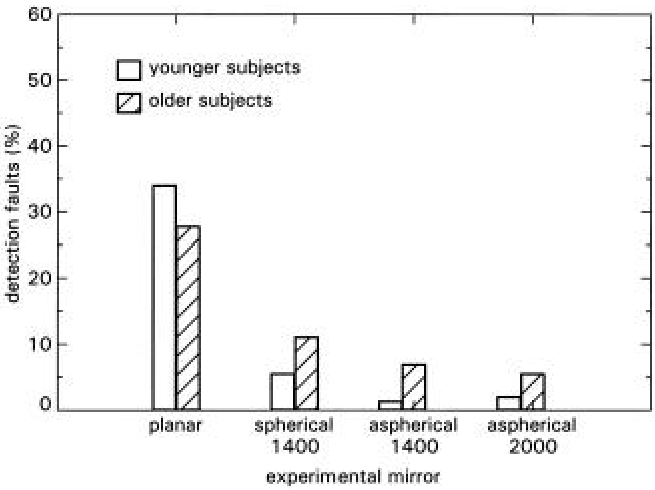

Figure 36 Detection faults for the four experimental mirror conditions, broken down according to 'age' group.

The interaction between the ‘experimental mirror’ and the ‘position of the second car’ is illustrated in Figure 37. When the second car was just behind the subject’s car or when the second car was in the direct field of view, there were no differences between the four mirror types. When there was just an overlap between the second car and the subject’s car, the percentage of detection faults for the planar mirror (54.2%) was much higher than for the non-planar mirrors (1.4% for the spherical mirror and the aspherical 1400 mm mirror and 0% for the aspherical 2000 mm) ($p<0.001$). When the second car was in the blind spot, similar differences between the planar mirror and the non-planar mirrors were found (planar mirror 48.6%, spherical mirror 25%, aspherical 1400 mm mirror 8.3%, aspherical 2000 mm mirror 9.7%) ($p<0.001$). Furthermore, a marginally significant difference between the spherical mirror and the aspherical 1400 mm mirror was found ($p<0.1$).

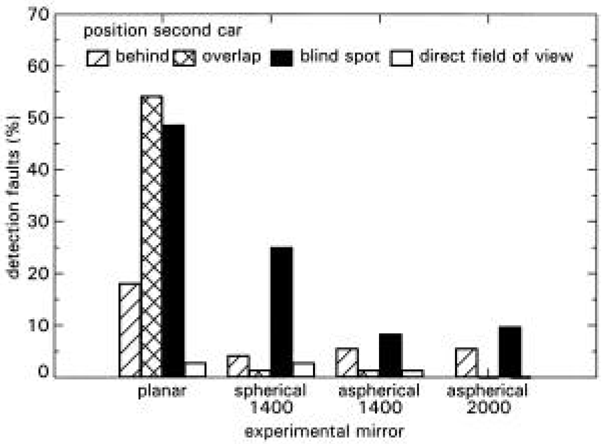

Figure 37 The percentage of detection faults for the four positions of the second car broken down for the four experimental mirror types.

As a check also the ‘false alarms’ were analyzed, i.e. when subjects indicated that there was a car in the adjacent lane, while there wasn’t. No effects of any of the experimental factors was found. On average, in 1% of the trials with the second car out of sight, the subjects mistakenly pressed the green or red button. The fact that this percentage is low shows that the subjects took the detection task seriously and did not merely guess or press a button at random.

Assessment of underlap/overlap

The overlap/underlap assessment faults (i.e. subjects indicated that they could not move to the other lane while in fact the other car was behind the subject's car or subjects indicated that they could move to the adjacent lane while in fact there was an overlap between the two cars) were submitted to an analysis of variance with factors ‘own mirror’ (planar, spherical, aspherical), ‘age’ (young, old), ‘experimental mirror’ (planar, spherical, aspherical 1400, aspherical 2000), ‘position of the second car’ (just behind the subject’s vehicle, just overlap with the subjects vehicle) and ‘replication’ (1..2). Main effect were found for the factors ‘own mirror’ [$F(2,30)=3.81$, $p<0.05$] and ‘age’ [$F(1,30)=6.75$, $p<0.05$]. No main effects were found for ‘experimental mirror’ [$F(3,90)=0.56$, n.s.], ‘position of the second car’ [$F(1,30)=1.98$, n.s.], ‘replication’ [$F(1,30)=0.87$, n.s.]. Interactions were found between ‘age’ and ‘position’ [$F(1,30)=6.42$, $p<0.05$] and between ‘experimental mirror’ and ‘position’ [$F(3,90)=8.17$, $p<0.001$].

A post hoc analysis of the differences between the three ‘own mirror’ categories showed that subjects with an aspherical mirror on their own car had a higher percentage of overlap/underlap faults than subjects with a spherical mirror on their own car ($p<0.05$): aspherical own mirror 33.3%, spherical own mirror 17.7%. The percentage of overlap/underlap faults for subjects with a planar mirror on their own car (27.6%) did not differ from the other two categories.

Older drivers made more overlap/underlap faults than younger drivers: 32.3% versus 20.1%. A post hoc analysis of the interaction between ‘age’ and ‘position of the second car’ showed that older drivers more often indicated that there was an overlap while in fact the second car was just behind: older drivers 49.3% versus younger drivers 15.3% ($p<0.05$). In case there was just an overlap between the two vehicles there was no significant difference between the two age groups (older drivers 15.3% and younger drivers 25.0%). This means that the harmless ‘better safe than sorry’ mistake of indicating that one could not move into the adjacent lane while in fact one could, was made more often by older drivers than by younger drivers. For the dangerous fault of indicating that one can move into the adjacent lane while in fact one can not there was no difference between older and younger drivers. (Figure 38)

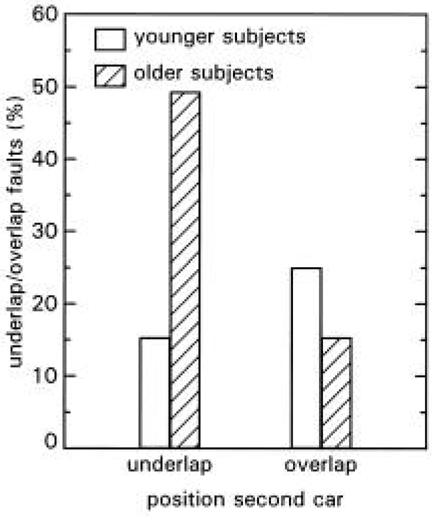

Figure 38 Underlap/overlap faults: interaction between underlap/overlap position and 'age' group.

A post hoc analysis of the interaction between ‘experimental mirror’ and ‘position’ showed that the harmless faults (red button, while the second car was just behind) are made more often in the planar mirror condition when compared to the two aspherical mirrors ($p<0.05$). For the planar mirror condition more harmless faults were found than dangerous faults (green button, while there was just an overlap between the two cars) (Figure 39). This indicates that in case of a planar experimental mirror drivers more often underestimated that gap than overestimated, while in case of non-planar mirrors drivers just as often made an underestimation as an overestimation.

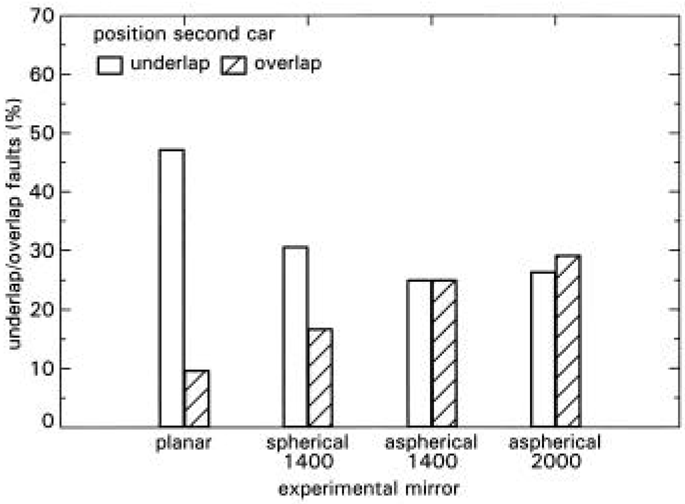

Figure 39 Underlap/overlap faults: the interaction between experimental mirror and underlap/overlap position.

5.2.3.2 Reaction time

The reaction time for the detection task (i.e. the time that elapsed between the moment the curtain was dropped and the subject pressed a button) was submitted to an analysis of variance with factors ‘own mirror’ (planar, spherical, aspherical), ‘age’ (young, old), ‘experimental mirror’ (planar, spherical, aspherical 1400, aspherical 2000), ‘position of the second car’ (out of view (2x), just behind the subject’s vehicle, just overlap with the subject's vehicle, in the planar mirror blind spot, in the direct field of view) and ‘replication’ (1..2). A main effect of the ‘position of the second car’ was found [F(5,150)=11.01, p<0.001]. No main effects were found for the factors ‘own mirror’ [F(2,30)=1.66, n.s.], ‘age’ [F(1,30)=1.77, n.s.], ‘experimental mirror’ [F(3,90)=1.18, n.s.] and ‘replication’ [F(1,30)=0.19, n.s.]. Significant second order interactions were found between ‘experimental mirror’ and ‘position of the second car’ [F(15,450)=1.88, p<0.05] and between ‘position of the second car’ and ‘replication’ [F(5,150)=3.01, p<0.05].

A post hoc analysis of the differences between the positions of the second car showed that the reaction time when the second car was out of view was shorter than the reaction time in case there was just an overlap between the two vehicles. Furthermore, the reaction time in case the second car was in the direct field of view was shorter than all of the other positions: second car out of view 1.50 s, second car just behind the subjects’ vehicle 1.63 s, just an overlap between the two vehicles 1.75 s, second car in the blind spot 1.61 s and the second car in the direct field of view 1.31 s.

A post hoc analysis of the interaction between ‘position of the second car’ and ‘experimental mirror’ showed that for none of the individual positions significant differences between the experimental mirrors were found. Similarly, a post hoc analysis of the interaction between ‘position of the second car’ and ‘replication’ showed that for none of the individual positions there was a difference between the two replications.

5.2.3.3 Drivers' glance behavior

Dwell time

The drivers’ dwell times in the direction of the driver’s side rearview mirror were submitted to an analysis of variance with factors ‘own mirror’ (planar, spherical, aspherical), ‘age’ (young, old), ‘experimental mirror’ (planar, spherical, aspherical 1400, aspherical 2000), ‘position of the second car’ (out of view (2x), just behind the subject’s vehicle, just overlap with the subjects vehicle, in the planar mirror blind spot, in the direct field of view) and ‘replication’ (1..2). A main effect of the position of the second car was found [F(5,150)=7.33, p<0.001]. None of the other factors showed a main effect (‘own mirror’ [F(2,30)=0.41, n.s.], ‘age’ [F(1,30)=0.62, n.s.], ‘experimental mirror’ [F(3,90)=0.62, n.s.], ‘replication’ [F(1,30)=0.01, n.s.]). A marginally significant interaction was found between ‘age’ and ‘position of the second vehicle’ [F(5,150)=1.93, p<0.1].
A post hoc comparison showed that the mirror dwell times for the conditions with the second car out of view (880 ms) or the second car in the direct field of view (814 ms) were shorter that the dwell times when the second car was just behind the subject’s vehicle (992 ms), just overlapping the subjects vehicle (990 ms) or in the planar mirror blind spot (947 ms). This effect seemed more pronounced for older drivers than for younger drivers.

Number of glances

The number of glances in the direction of the driver’s side rearview mirror were submitted to an analysis of variance with factors ‘own mirror’ (planar, spherical, aspherical), ‘age’ (young, old), ‘experimental mirror’ (planar, spherical, aspherical 1400, aspherical 2000), ‘position of the second car’ (out of view (2x), just behind the subject’s vehicle, just overlap with the subject's vehicle, in the planar mirror blind spot, in the direct field of view) and ‘replication’ (1..2). Main effects were found for the factors ‘own mirror’ [F(2,30)=4.51, p<0.05] and ‘position of the second car’ [F(5,150)=3.10, p<0.05]. Furthermore, there was an interaction between ‘own mirror’ and ‘replication’ [F(2,30)=4.00, p<0.05]. For the detection task, subjects having a spherical mirror on their own car sampled the driver’s side mirror 1.3 times on average, while subjects with a planar mirror or spherical mirror on their own car sampled the driver’s side mirror 1,1 times on average. For the second replication this difference was even more pronounced than for the first replication.

A post hoc comparison of the effect of position showed that when the second car was in the direct field of view, the driver's side mirror was sampled less often (1.06 times) than when the second car just overlapped the subject's vehicle (1.22) or it was out of view (1.19).

5.3 Discussion and conclusions field experiment

The results of the 'last safe gap' task confirmed that, in general, drivers accept smaller gaps in case of non-planar mirrors, due to the image size reduction. When driving with non-planar mirrors, drivers who were used to non-planar mirrors did in general not accept larger gaps than drivers who were used to planar mirrors, with the exception of one combination: When drivers with a spherical spherical mirror on their own car drove with the experimental spherical mirror, the last safe gap was the same as the last safe gap when driving with a planar experimental mirror. This is in line with the result that drivers with a spherical convex mirror on their own car sample their mirror more often than drivers with a planar mirror on their own car. In other words, drivers with a spherical convex mirror are more aware that the interpretation of the information provided by the driver's side mirror is not straight forward, for which they compensate by checking the mirror more often. In this context it should be noted that the experiment considered the 'worst case' scenario where the driver is not able to use the inner mirror as a check. Of course, if the experiment had shown that drivers who are used to non-planar mirrors do compensate for the image reduction of non-planar mirrors even without the use of the inner mirror, this would have been a very strong case in favor of non-planar mirrors. The results of the first phase of the study contain evidence that the situation with inner mirror available might be more positive: in the questionnaires drivers indicated that they think it is important to check more than one mirror, while the survey of mirror characteristics shows that although non-planar inner mirrors are allowed, only planar inner mirrors are installed allowing a proper check of the gap with respect to vehicle approaching from behind.

In an absolute sense, the reduction of the time gap due to non-planar mirrors is not dramatic when compared to the effect of the approach speed of the car coming from behind: averaged over both approach speeds, the planar mirror resulted in a time gap of 4.4 s, the spherical convex mirror in 3.8 s, the aspherical 1400 mirror in 3.7 s and the aspherical 2000 mirror in 4.0 s, while averaged over all mirror types the speed difference of 20 km/h resulted in a time gap of 5.1 s and the speed difference of 50 km/h resulted in a time gap of 2.9 s.

It is striking that the drivers used to spherical non-planar mirrors do compensate for the image reduction and that drivers who are used to aspherical convex mirrors do not compensate for the image reduction of an aspherical mirror, as the image of a car appoaching from behind is more or less the same in both spherical and aspherical mirrors (a car at larger distance is visible in the spherical part of the aspherical mirrors). An assumption could be that due to the fact that aspherical mirrors were introduced more recently than spherical mirrors, the subjects with a spherical mirror on their own car had more experience than the subjects with aspherical mirrors. However, if this would be the case, it could be argued whether it is acceptable that drivers are only able to compensate after many years of experience.

Results of the 'vehicle detection task' show that non-planar mirrors give a vast reduction of the number of detection faults: from more than 30% in case of a planar mirror to less than 10% in case of non-planar mirrors. No signs were found that this would go to the expense of an increase in reaction time or visual workload. When the most critical position, the blind spot, is considered, there is also a distiction between the different types of non-planar mirrors: the aspherical mirrors show even a greater improvement than the spherical convex mirror (planar mirror 49% detection faults, spherical 25%, aspherical 1400 8%, aspherical 2000 10%). With respect to older drivers a question was whether non-planar mirror would provide a special benefit for older drivers as they have problems turning their head or whether non-planar mirrors would provide a disadvantage as they would be more difficult for them to interpret. If the first effect were dominant, it would be expected that the improvement with non-planar mirrors would be greater for older drivers than for younger drivers. However, the results suggest that the improvement in detection performance with non-planar mirrors is less for older drivers than for younger drivers, which leads to the conclusion that the second effect is dominant.

With respect to the assessment of whether or not it is possible to move in front of a vehicle at close range in the other lane, the results show that, in general, the estimation errors are not affected by mirror type, but in case of non-planar mirrors the average distance estimate is somewhat shorter, which may lead to more critical situations.

In summary, it can be concluded that drivers do accept smaller margins with non-planar mirrors than with of planar mirrors. Only drivers who are used to driving with a spherical convex mirror compensate for the reduced image size in a spherical convex mirror and maintain the same margin in case of spherical convex and planar mirrors. On the other hand, the results confirm that non-planar mirrors improve the detection performance, without an increase in visual workload.

6 OVERALL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The inventory of the mirror characteristics of vehicles on the road in the Netherlands showed that more than half of the vehicles had non planar driver's side mirrors of which 60% were spherically convex and 40% were aspherical. Passenger's side mirrors are predominantly spherically convex (92%). The distribution of the radii of curvature of driver's side spherically convex mirrors showed peaks around 1400 mm and 2000 mm, while also some mirrors were found with a radius of curvature in the range of 3000 to 4500 mm. For the radius of curvature of aspherical driver's side mirrors a peak was found around 2000 and 2100 mm, while a peak around 1400 mm was found for cars which were registered since 1998.

Although aspherical mirrors were mainly introduced on high end cars, the top five of cars registered in 1997 showed that aspherical mirrors were also becoming common on popular medium and small cars.
Fields of view of the non-planar mirrors within a sample of nine cars (including the five best sold cars in the Netherlands, see par. 2.3.2) were almost twice as large as the fields of view of the planar mirrors. Due to the larger radius of curvature for the aspherical mirrors (2000 mm) when compared to the spherical mirrors (1400 mm), the fields of view of the aspherical mirrors were only slightly larger. Based on the inventory of mirror characteristics four mirror types were included in the experimental part of the study: planar, spherically convex with a radius of curvature of 1400 mm and two aspherical mirrors, i.e. one aspherical mirror with a radius of curvature of the spherical part of 1400 mm and one with a 2000 mm radius.

The results of the exploratory questionnaire showed that:

- When changing lanes older drivers look over their shoulder less often than younger drivers,
- The extent to which drivers turn their head reduces with increasing mirror convexity,
- When changing lanes, younger drivers feel more safe and confident in case of non-planar mirrors, whereas older drivers feel less safe and confident in case of non-planar mirrors,
- Younger drivers feel to be better able to estimate distance than older drivers,
- A considerable proportion of drivers with aspherical mirrors are aware of the special characteristics of their mirrors,
- Half the respondents accurately knew what type of mirror they had, a quarter said they did not know, a quarter thought they had a planar driver's side mirror, while in fact it was convex and only a very small proportion thought the mirror was convex while it was flat.
- Drivers with non-planar mirrors have a higher preference for their present mirrors when compared to their previous mirrors than drivers with flat mirrors.

The results of the large sample questionnaire showed the following driver's side mirror type related effects:

- Younger drivers with non-planar driver's side mirrors turn their head less often than younger drivers with flat mirrors. Older drivers with aspherical mirrors turn their head more often when compared to older drivers with flat or spherical mirrors.
- Drivers with aspherical or flat mirrors think they are better able to assess gaps than drivers with spherical convex mirrors.
- Less than half the drivers correctly knew the optical effects of their driver's side mirror and just about one third knew what optical type of mirror they had.
- Drivers with non-planar mirrors experience less headlight glare in their driver's side mirror than drivers with flat mirrors.

The results of the field experiment showed that non-planar rearview mirrors still imply a trade off between on the one hand improved detection due to the larger field of view and on the other hand smaller gaps being accepted due to image reduction. Driver's experience with non-planar mirrors did not generally compensate for the negative effect, with the exception of drivers who were accustomed to spherical convex mirrors. Those drivers compensated for the image reduction of spherical convex mirrrors and accepted the same gaps with planar and spherical mirrors. Negative effects on the effort required to process the mirror information were not found. A factor that was deliberately not considered in the present experiment was the role of the (planar) inner mirror in gap assessment. The worst case situation was considered, i.e. the inner mirror could not be used to check the gap. This situation is relevant when the field of view of the inner mirror is blocked by objects in the back of the car, or when a driver has to make a very quick assessment and lacks the time to check the inner mirror, for example in case of an emergency maneuver. Whether drivers are able to use the inner mirror to compensate for the image reduction of non-planar driver's side mirrors could be revealed by a field experiment in which the availability of the inner mirror is included as an experimental factor (with / without inner mirror). If such an experiment would be conducted it could also be investigated how the visual sampling behavior is influenced by the inner mirror, e.g. the inner mirror may be sampled in addition to the outer mirror or the glances at the inner mirror replace part of the glances at the outer mirror.

The question remains how to compare the relative weight of the beneficial effect of improved detection performance against the disadvantage of decreased gap margins. In this trade off an important factor is the extent to which the driver in the adjacent lane can control the situation in order to compensate for an improper lane change. In case of an improper gap assessment, the car coming from behind should easily be able to perceive the improper intention of the car ahead to change lanes because it is in the field of view straight ahead. Consequently, the driver coming from behind could brake or make an evasive maneuver. In case a car at close range in the blind spot is not detected, both perception of the lane change maneuver and the possibilities for safe evasive actions are more limited. Therefore, the improved detection is more important than the decrease in gap acceptance. This leads to the conclusion that the use of non-planar driver's side rearview mirrors should be beneficial for safety.

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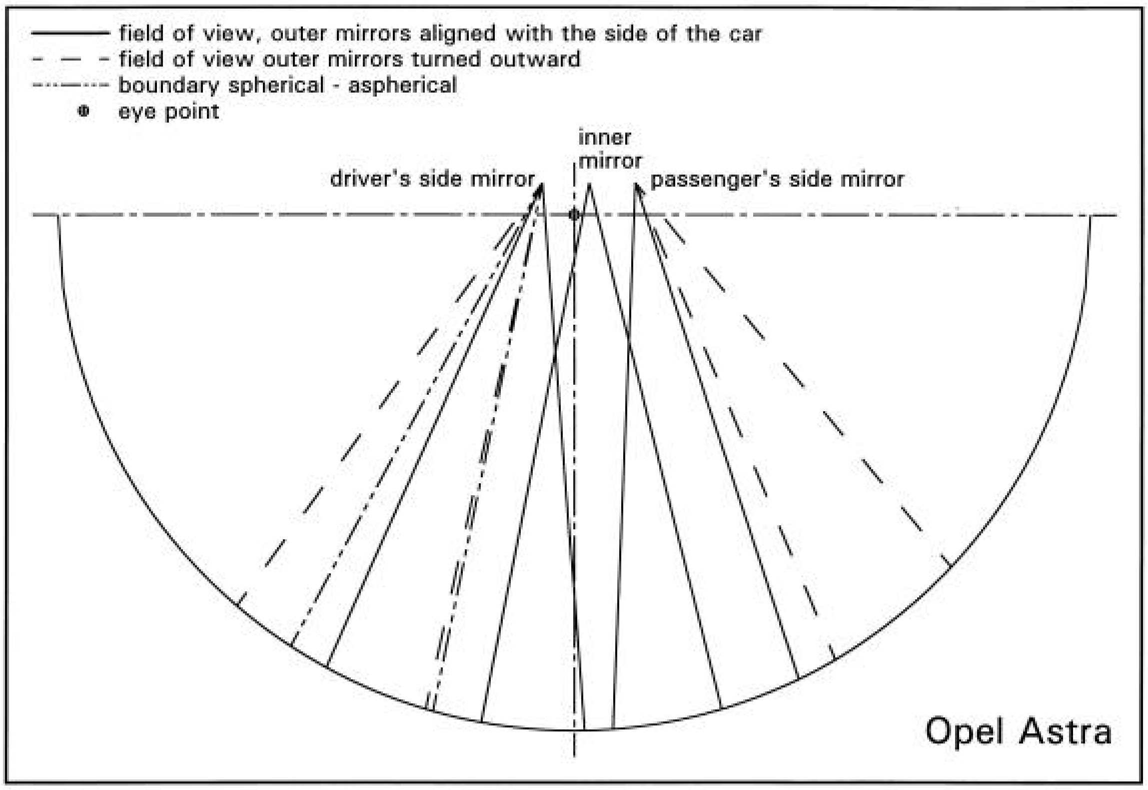
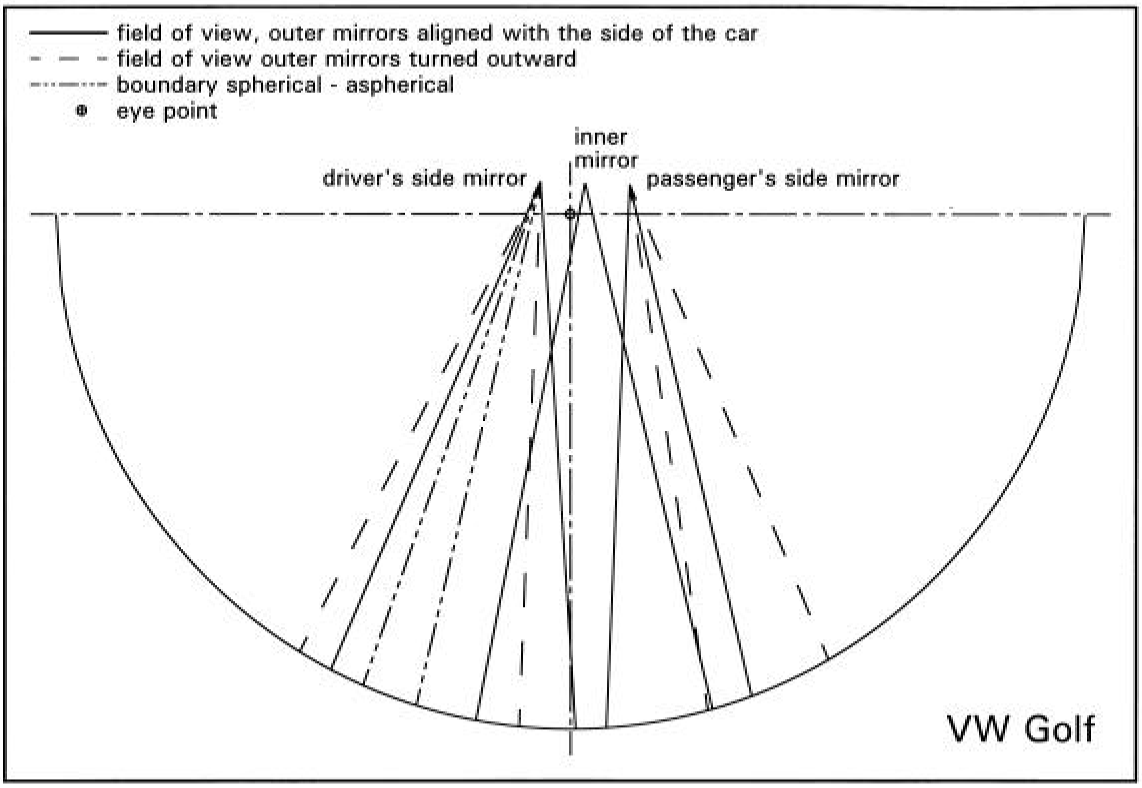
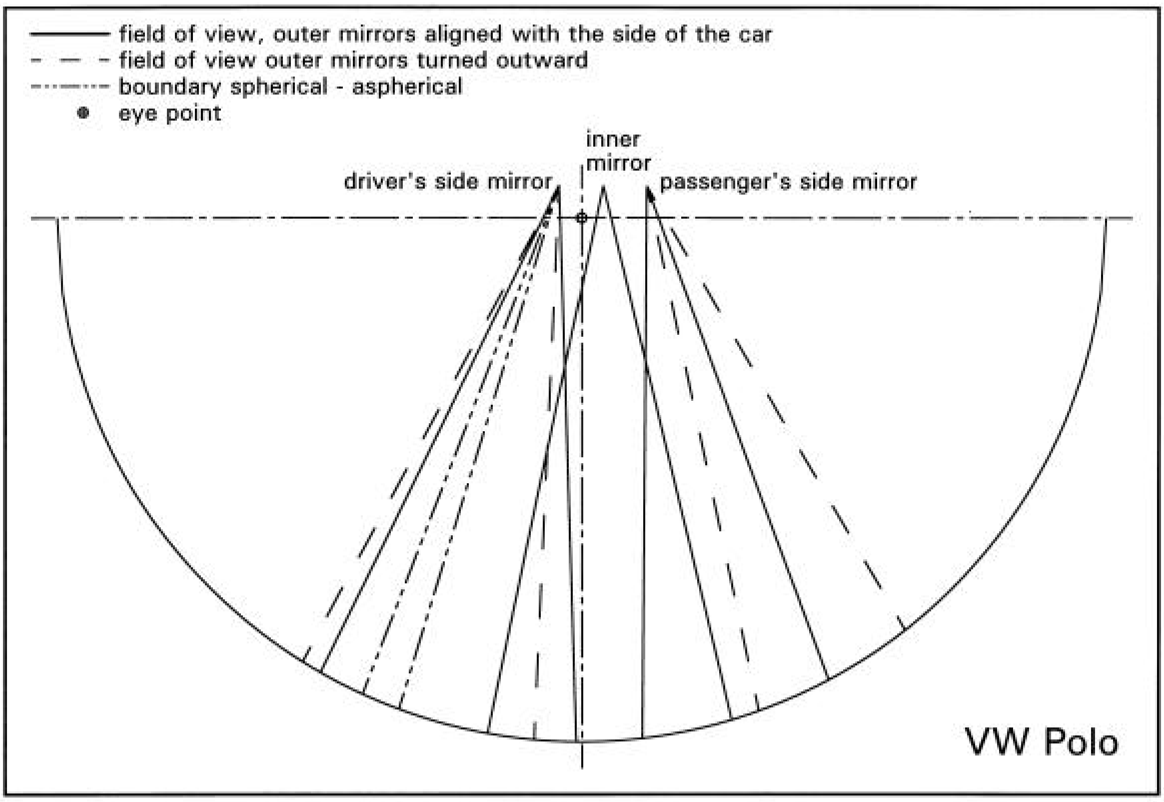
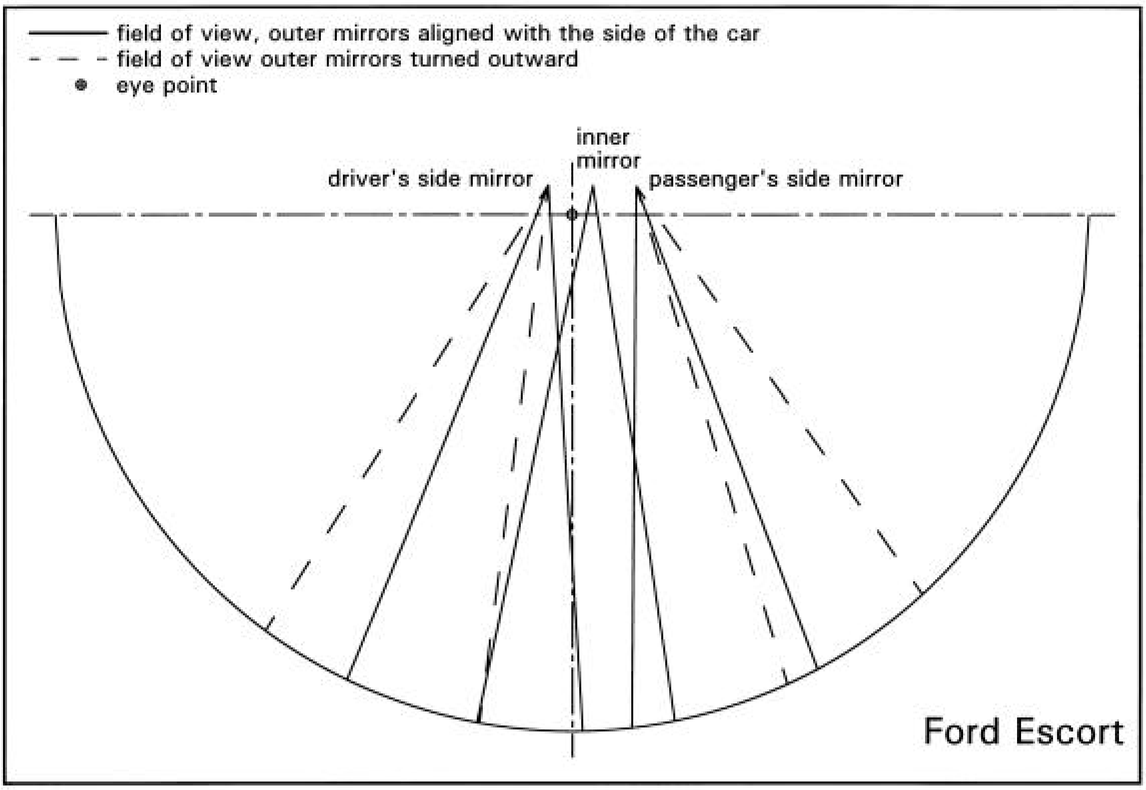
APPENDICES

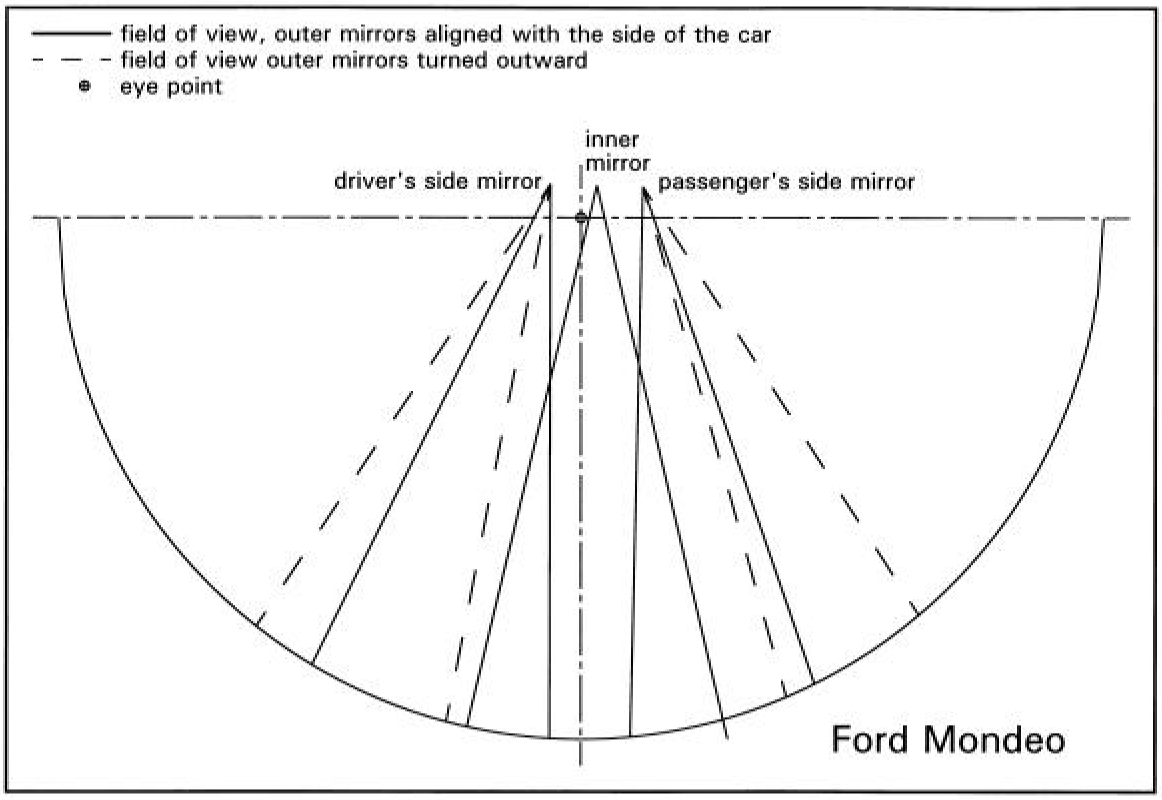
APPENDIX A: **Rearward fields of view**

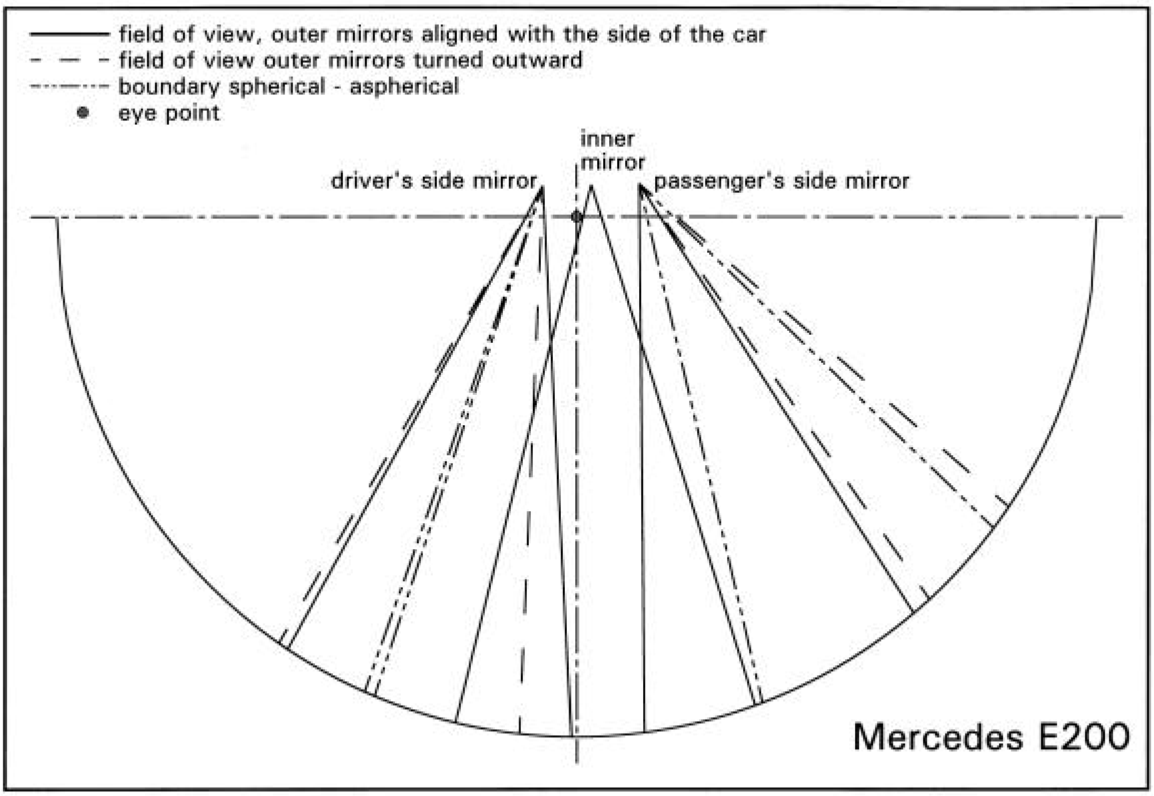


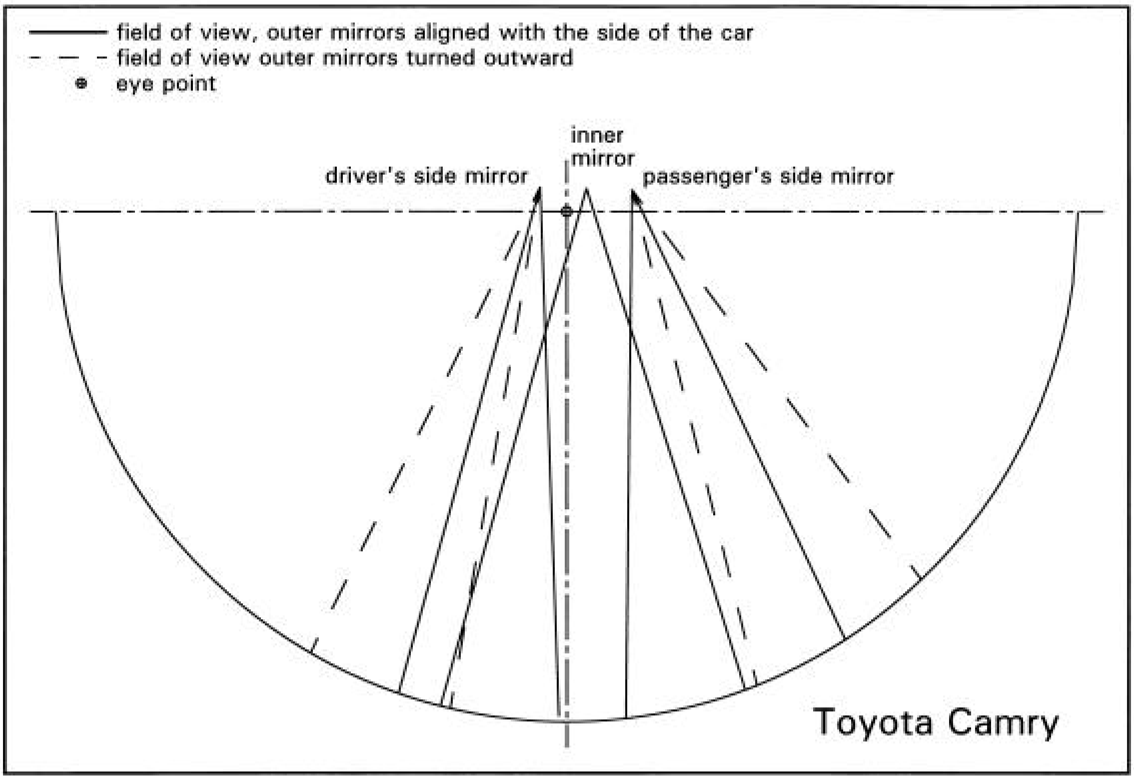


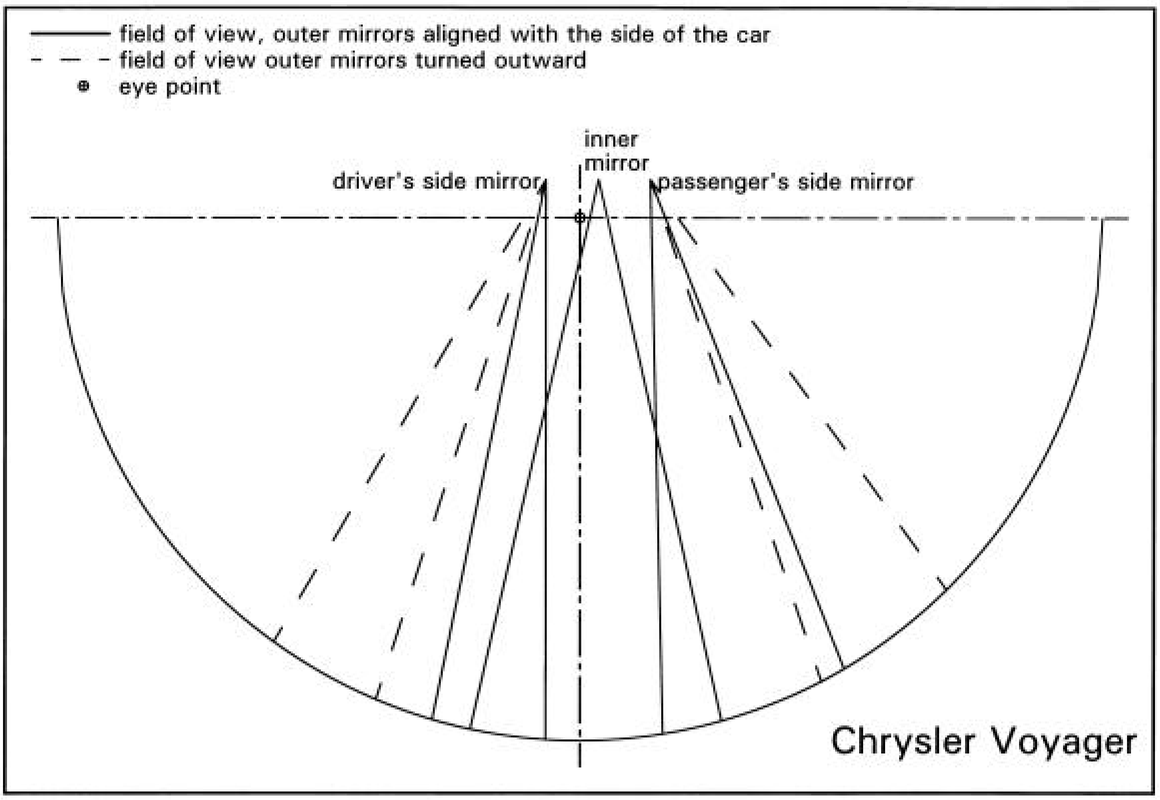

field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
boundary spherical - aspherical
eye point
inner mirror
driver's side mirror
passenger's side mirror
VW Polo

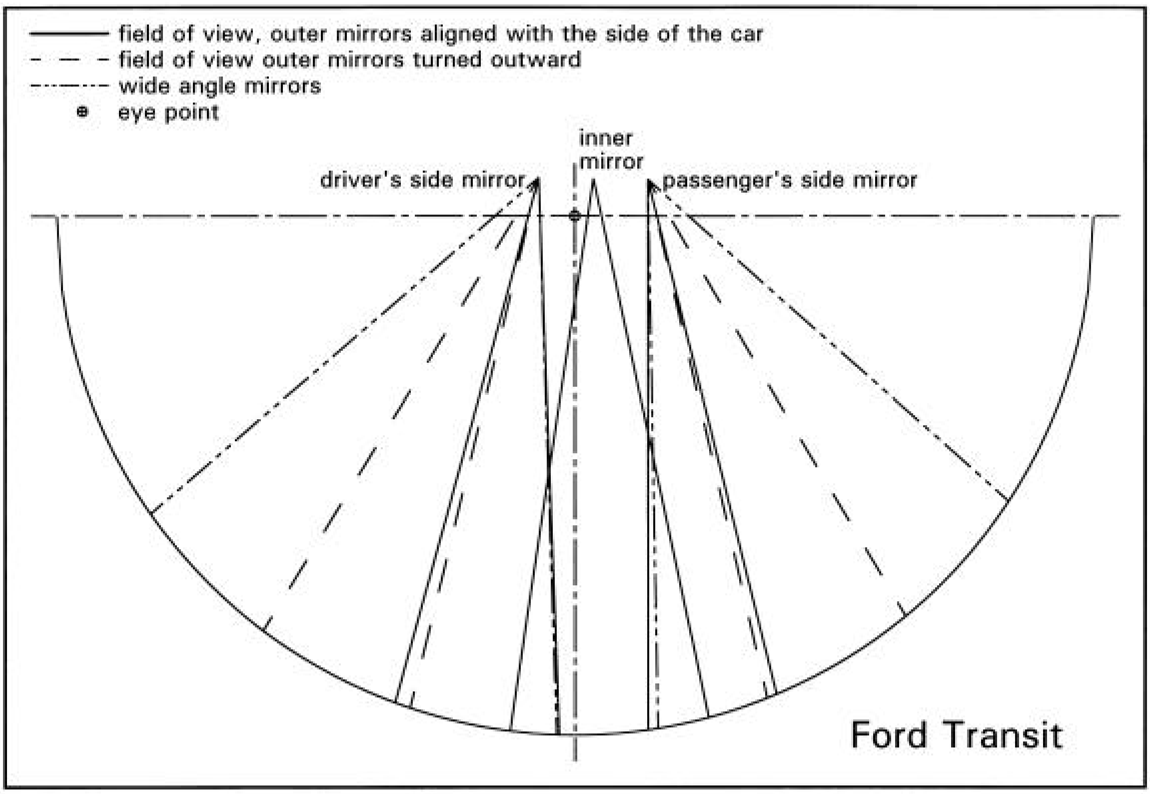

field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
eye point
inner mirror
driver's side mirror
passenger's side mirror
Ford Escort


field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
eye point
inner mirror
driver's side mirror
passenger's side mirror
Ford Mondeo


field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
boundary spherical - aspherical
eye point
inner mirror
driver's side mirror
passenger's side mirror
Mercedes E200


field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
eye point
inner mirror
driver's side mirror
passenger's side mirror
Toyota Camry


field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
eye point
inner mirror
driver's side mirror
passenger's side mirror
Chrysler Voyager



field of view, outer mirrors aligned with the side of the car
field of view outer mirrors turned outward
wide angle mirrors
eye point
inner mirror
driver's side mirror
passenger's side mirror
Ford Transit

APPENDIX B: **Exploratory questionnaire** (Translated in English; original version in Dutch)

QUESTIONNAIRE ON TRAFFIC SAFETY

We would very much appreciate if you would answer the following questions. Your responses will be dealt with in strict anonymity.

On some questions you can tick one of five responses. If you think an answer applies perfectly, tick the box directly next to it.
If you think an answer is more or less applicable tick the box on that side just next to the middle, e.g.:

never		X				always

If do not have an opinion, tick the middle box.

Please answer the questions swiftly and in the given order. Do not return to questions after you answered them.

(1) In what kind of car do you drive?
Make: ....
Type: ....
Year: ....
Registration: ....

(2) How long have you been driving this car? .... years

(3) What kind of car did you drive before this one?
Make: ....
Type: ....
Year: ....
Registration: ....

(4) Do you always drive the same car or do you drive various cars?
0 Always the same car
0 Various cars
Please indicate make, type and year of other cars, as well as how often you drive these cars:
....
....
....

Please keep the car you drive most in mind as you answer the following questions
i.e. Make ...., Type ...., Year...........

(5) Do you check / adjust your mirrors before you drive?

rearview inner mirror

never						always

righthand outside mirror

never						always

driver's side mirror

never						always

Reason / comments (e.g. different users):

....

(6) Do you align your driver's side mirror in a specific way?

....
....

(7) When you are going to pass another vehicle or change lanes to the left, which mirror(s) do you use?

rearview inner mirror

never						always

driver's side mirror

never						always

(8) When you are going to pass another vehicle or change lanes to the left, do you look over your shoulder?

never						always

(9) Are you able to safely pass another vehicle or change lanes to the left by looking only in your **rearview inner mirror**?

0 Yes
0 No

(10) Are you able to safely pass another vehicle or change lanes to the left by looking only in your **driver's side mirror**?

0 Yes
0 No

(11) When you want to pass or change lanes to the left in case of heavy traffic behind you, do you use a specific criterion to decide whether you can overtake or not?

....
....
....

(12) How safe do you feel when you pass other vehicles or change lanes to the left in heavy traffic?

unsafe						safe

(13) Are you always confident whether it is safe when you pass another vehicle or change lanes to the left in heavy traffic?

uncertain						confident

(14) Do you trust the information you receive via your mirrors?

rearview inner mirror

distrust						trust

driver's side mirror

distrust						trust

(15) Are you able to properly estimate the distance and speed of cars coming from behind?

Estimating distance

badly | | | | | | very well

Estimating speed

badly | | | | | | very well

(16) Do you notice a difference in difficulty of estimating the distance and speed of vehicles coming from behind during daylight or darkness?

0 No difference between daylight and darkness

0 There is a difference between daylight and darkness: in the *dark* it is easier to estimate distance and speed

0 There is a difference between daylight and darkness: in *daylight* it is easier to estimate distance and speed

(17) When you look into your driver's side mirror do you check it once or several times?

0 Do not check driver's side mirror

0 Look once

0 Look several times

(18) When you look over your shoulder before going to the left, do you check once or several times?

0 Do not look over shoulder

0 Look once

0 Look several times

(19) Has it ever happened to you that a car was in your blind spot when you overtook or changed lanes to the left?

never | | | | | | often

If this happened:

(20) Did it result in a serious situation?

not serious | | | | | | serious

(21) What was the cause? (if applicable, tick more than one answer)

0 The car beside/behind was driving too fast
0 You were driving too fast
0 You did not look in your mirror
0 You did not look over your shoulder
0 You saw the car, but you made an improper assessment
0 You did look in your mirror, but you did not see the other car
0 Other, ...

(22) While changing lanes have you ever made a wrong assessment of the speed of a car coming from behind and you moved to the left while you shouldn't?

never						often

If this ever happened:

(23) Did it result in a serious situation?

not serious						serious

(24) What was the cause? (if applicable, tick more than one answer)

0 The car beside/behind was driving too fast
0 You were driving too fast
0 You did not look in your mirror
0 You did not look over your shoulder
0 You saw the car, but you made an improper assessment
0 You did look in your mirror, but you did not see the other car
0 Other, ...

(25) When stepping out of your car, do you check your mirrors and/or look over your shoulder? (if applicable, tick more than one answer)

0 Inner mirror
0 Left outside mirror
0 Look over your shoulder

(26) Do you use your mirrors when backing into a parking space and/or do you turn your head? (if applicable, tick more than one answer)

0 Inner mirror
0 Outside mirrors
0 Turn head

(27) Do you look in your mirrors and/or do you look behind when pulling away from the side of the road? (if applicable, tick more than one answer)

0 Inner mirror
0 Outside mirrors
0 Look behind

(28) When changing lanes to the left do you use your rearview inner mirror to check whether the car you see in your driver's side mirror is far enough behind you?

0 Yes
0 No
0 ....

(29) Did you notice something peculiar about the driver's side mirror of your present car?

0 No
0 Yes
If so what? ....

(30) Is there a difference between your driver's side mirror and your rearview inner mirror?

0 No difference
0 Yes there is a difference
0 Don't know
If so what? ....

(31) Is there a difference between the left outside mirror of your present car and your previous car?

0 No difference
0 Yes there is a difference
0 Don't know
If so what? ....

(32) Did you have any problems getting used to the driver's side mirror of your new car?

not difficult						very problematic

(33) If you could chose, would you prefer the driver's side mirror of your present car or your previous car?

Prefer previous driver's side mirror						Prefer present driver's side mirror

(34) Do you know whether your driver's side mirror is planar or **convex**?

0 Planar
0 Convex; constant curvature (spherical)
0 Convex; varying curvature (aspherical)
0 Don't know

(35) Do you know what the difference is between planar and convex mirrors?

0 No
0 Yes
If so what? ....

(36) Please answer the following questions if you have a driver's side mirror of which the outer part has a stronger curvature than the rest of the mirror (aspherical mirror; most times a thin vertical line is etched in the mirror):

Do you have a certain strategy when using this mirror?
0 No
0 Yes
If so what? ....

Do you use the inner and outer part of this mirror in different ways?
0 No
0 Yes
If so how? ....
Usage inner part: ....
Usage outer part: ....

If you see a car in the outer part of your mirror left of the thin line, can you move to the left?
0 Yes
0 No
0 ....

(37) Do you pay any attention to the rearview mirrors when buying a new car?

0 Do not pay any attention to mirrors
0 Do pay attention, but it does not affect choice of car
0 Rearview mirrors do play a role in choosing a car

(38) Is your car equipped with additional devices to improve the field of view besides and behind your car, other than the rearview mirrors?

0 Separate convex mirror attached in the corner of the left outside mirror
0 'Fishbowl'sheet on rear window
0 ....

(39) Where you involved in an accident in the past five years?

0 No
0 Yes

If so, what kind of accident(s)?

....
....

What type of car did you drive when you had the accident?
Make:............, Type:..............., Year:...............

(40) Do you wear glasses or contact lenses?

0 Glasses
0 Contact lenses

Are these for

0 Short distances / reading
0 Long distances
0 Both nearby and distances and if so:
  0 Separate glasses
  0 Bifocal lenses
  0 Progressive lenses

Prescription: ....

Do you have a cylindric correction?

0 No
0 Yes
0 Don't know

(41) Do you have a limited field of vision?

0 No
0 Yes
If so, how? ....

(42) Do you suffer from car-sickness?

0 No
0 Yes
If so, to what extent? ....

(43) Do you have difficulties turning your head?

0 No
0 Yes
If so, to what extent? ....

(44) How far do you have to turn your head to check your blind spot?

hardly | | | | | | fully turned

(45) How close do you follow a car in front when driving on a highway in heavy traffic?

0 At 1 car length
0 At 2 car lengths
0 At ... feet
0 ....

(46) At what speed do you drive?

0 Slower than posted speed, i.e. " ..... km/h below posted speed
0 At about the posted speed
0 Faster than the posted speed, i.e. " ..... km/h faster

(47) What is your age? ...years

(48) What type of drivers license do you have (please circle)? A (car)
B (motorcycle)
C (truck)
D (bus)
E (trailer)

(49) How many years of driving experience do you have? .... years

(50) How many miles do you drive per year? .... km/year

(51) What type of roads do you usually drive? (if applicable, tick more than one answer)

0 Urban roads
0 Rural roads
0 Highway

(52) What is your profession? ....

(53) What is your height? .... m

(54) Sex: 0 woman
0 man

Do you have any other remarks about rear view mirrors and their use??

....
....

APPENDIX C: **Short questionnaire (Translated in English; original version in Dutch. The number of responses are indicated behind each item in parentheses)**

QUESTIONNAIRE ON TRAFFIC SAFETY

We would very much appreciate if you would answer the following questions. Your responses will be dealt with in strict anonymity.

On some questions you can choose from various options. Tick the answer that you think applies best. Darken the relevant circle completely. Please make your marks as follows: Like this: ?, Not like this: ? ?

Please answer the questions in the given order. Do not return to questions after you answered them.

(1) In what kind of car do you drive?

Make: ....

Type: ....

Year: ....

Registration: ....

(2) How long have you driven this car?

.... years / .... months

.... kilometers

(3) Do you always drive the same car or do you drive various cars? (208)

? (173) (Almost) always this car

? (0) (Almost) always another car

? (35) Various cars

Please keep the car you drive now in mind as you answer below questions

(4) Do you adjust your mirrors before you drive?

	never	almost never	sometimes	almost always	always
Rearview inner mirror (207)	? (28)	? (46)	? (60)	? (33)	? (40)
Driver's side mirror (205)	? (38)	? (43)	? (69)	? (25)	? (30)
Passenger's side mirror (199)	? (45)	? (56)	? (58)	? (20)	? (20)

(5) Are you almost the only person driving this car or are more people driving this car? (208)

? (151) (Almost) only person driving this car

? (57) Multiple drivers

(6) How do you align your driver's side mirror? (207)

? (135) So I can see a part of my own car as a reference

? (62) As far as possible outward to minimize blind spots

? (10) Other, ...

(7) When you are going to pass another vehicle or change lanes to the left, which (combination of) information do you use?

A To check for vehicles *behind*?

	never	almost never	sometimes	almost always	always
Rearview inner mirror (208)	? (9)	? (0)	? (9)	? (42)	? (148)
Driver's side mirror (208)	? (10)	? (1)	? (1)	? (27)	? (169)
Turn head (208)	? (38)	? (14)	? (29)	? (37)	? (90)

B To check for vehicles *beside* your car?

	never	almost never	sometimes	almost always	always
Rearview inner mirror (208)	? (102)	?(17)	? (18)	? (19)	? (52)
Driver's side mirror (208)	? (19)	? (4)	? (16)	? (30)	? (139)
Turn head (208)	? (13)	? (3)	? (19)	? (42)	? (131)

C To *assess the distance and speed* of vehicles approaching from behind?

	never	almost never	sometimes	almost always	always
Rearview inner mirror (208)	? (7)	? (1)	? (8)	? (44)	? (148)
Driver's side mirror (208)	? (22)	? (6)	? (28)	? (49)	? (103)
Turn head (208)	? (107)	? (24)	? (26)	? (18)	? (33)

(8) Are you always confident whether it is safe when you pass another vehicle or change lanes to the left in heavy traffic (please answer both for daylight and at night)?

	absolutely uncertain	uncertain	somewhat confident	confident	absolutely confident
Daylight (207)	? (3)	? (0)	? (6)	? (103)	? (95)
Dark (205)	? (3)	? (1)	? (17)	? (89)	? (95)

(9) Do you trust the information you receive via your mirrors (please answer both for daylight and at night)?

rearview inner mirror

	absolutely distrust	distrust	somewhat trust	trust	absolutely trust
Daylight (207)	? (0)	? (1)	? (18)	? (110)	? (78)
Dark (203)	? (0)	? (7)	? (30)	? (100)	? (66)

driver's side mirror

	absolutely distrust	distrust	somewhat trust	trust	absolutely trust
Daylight (206)	? (0)	? (4)	? (29)	? (111)	? (62)
Dark (203)	? (0)	? (6)	? (39)	? (100)	? (58)

(10) Are you able to properly estimate the distance and speed of cars coming from behind?

	very badly	badly	just	well	very well
Estimating distance (206)	? (0)	? (2)	? (14)	? (143)	? (47)
Estimating speed (206)	? (1)	? (6)	? (22)	? (147)	? (30)

(11) Do you wait to change lanes until there are extra large gaps to other traffic because you do not trust the traffic information in the mirror (please answer both for daylight and at night)?

	never	almost never	sometimes	almost always	always
Daylight (205)	? (35)	? (56)	? (50)	? (45)	? (19)
Dark (203)	? (28)	? (42)	? (61)	? (41)	? (31)

(12) Do you step on the accelerator and speed up when you are changing lanes (please answer both for daylight and at night)?

	never	almost never	sometimes	almost always	always
Daylight (206)	? (2)	? (11)	? (69)	? (79)	? (45)
Dark (204)	? (3)	? (14)	? (64)	? (78)	? (45)

(13) Has it ever happened to you in the last six months, or as long as you had your present car if this was shorter, that you had a close call (e.g. the other car honked their horn) or actual crash because a car was in your blind spot (i.e. the car was not visible in your mirrors) when you overtook or changed lanes to the left? (208)

never	almost never	sometimes	often	very often
? (124)	? (67)	? (16)	? (1)	? (0)

(14) In the last six months, or as long as you had your present car if this was shorter, have you ever had a close call or actual crash while changing lanes because you saw a vehicle in your mirror but made a wrong assessment of the safe gap when judging the closing speed of a car coming from behind and you moved to the left while you shouldn't? (206)

never	almost never	sometimes	often	very often
? (162)	? (35)	? (7)	? (1)	? (1)

(15) Does your driver's side mirror modify the scene? (206)

? (105) no

? (64) driver's side mirror minifies image (objects seem smaller or further away than they really are)

? (13) driver's side mirror magnifies image (objects seem larger or closer by than they really are)

? (3) driver's side mirror distorts image (the shape of objects is changed in the mirror)

? (21) don't know

(16) Please give your responses to the following questions by ticking the applicable boxes in the table underneath.

A Do you know whether the driver's side mirror on your present car is planar or non-planar? (206)

B Do you know whether the driver's side mirror on your previous car was planar or non-planar? (160)

C If relevant, do you know whether the driver's side mirror on another car you currently drive often is planar or non-planar? (86)

type of optical design	top view cross section	A present car	B previous car	C other car
planar		? (128)	? (90)	? (30)
convex (constant convexity)		? (12)	? (12)	? (4)
concave / hollow (constant concavity)		? (9)	? (4)	? (1)
aspherical (varying curvature)		? (16)	? (4)	? (6)
don't know		? (40)	? (50)	? (45)

(17) How long did it take you to get used to your present car's driver's side mirror after you first drove this vehicle? (204)

? (146) no time needed to get used to present mirrors

? (37) about one day

? (17) about one week

? (1) about one month

? (3) about half a year

? (0) about one year

? (0) more than one year

? (0) other, ...

(18) Please rate how comfortable you feel using the driver's side mirror on your present car: (205)

very comfortable	comfortable	marginally comfortable	marginally uncomfortable	uncomfortable	very uncomfortable
? (42)	? (125)	? (23)	? (6)	? (6)	? (3)

(19) Please rate the headlight glare in the driver's side mirror you experience at night: (201)

very acceptable	acceptable	marginally acceptable	marginally uncomfortable	uncomfortable	very uncomfortable
? (31)	? (100)	? (23)	? (23)	? (20)	? (4)

(20) If you could chose, what kind of driver's side mirror would you prefer? (188)

? (90) Planar

? (12) Convex; curved with constant radius

? (29) Aspherical; curved with varying radius

? (57) Don't care

(21) Please answer the following questions if you have a driver's side mirror in which a thin vertical line is etched at about 1/4 from the outer edge.

Do you have a certain strategy when using this mirror? (41)

? (34) No

? (7) Yes

If so what? ....

Do you use the inner and outer part of this mirror in different ways? (42)

? (32) No

? (10) Yes

If so how? ....

Usage inner part: ....

Usage outer part: ....

If you see a car in the outer part of your mirror left of the thin line, can you move to the left? (41)

? (4) Yes

? (33) No

? (4) ....

(22) Do you wear glasses or contact lenses? (129)

? (114) Glasses

? (15) Contact lenses

Are these for

? (18) Short distances / reading

? (50) Long distances

? (59) Both nearby and distances and if so:

? (4) Separate glasses

? (16) Bifocal lenses

? (39) Progressive lenses

(23) What is your age? ... years

(24) Sex: (208) ? (68) woman

? (140) man

Please answer question 26 in case you are only visiting the Netherlands for a short period or in case you have been living in the Netherlands for less than three years.

(25) Are you living in the Netherlands or are you visiting the Netherlands for a short period? (5)

? (2) I am visiting for .... days

? (3) I have been living in the Netherlands for .... months

Which country do come from? ....

(26) Do you have any other remarks about rear view mirrors and their use??

....

....

APPENDIX D: **Subject's instruction field experiment (Translation in English; original version in Dutch)**

You are about to take part in an experiment with the research vehicle. You will drive from Soesterberg to the Flevopolder. During the journey you can get used to the car. Half way you will change places with the other participant (one of you will drive the gray car). The study will take place at a quiet road in the polder.

During the experiment the inner mirror and the passenger's side mirror will be turned away. Always adjust your driver's side mirror in such a way that the rear edge of the door is just visible.

The research vehicle will drive at a moderate constant speed. You will only have to accelerate, after which the experimenter will switch on the cruise control and the car itself will control the driving speed. At all times you will be able to brake or accelerate for safety reasons. You will drive in the right lane and keep the vehicle properly in the middle of the lane.

Circles are painted on the road surface, to the right side on the emergency lane. These circles have an opening on one side: either left, right, top or bottom. You will look ahead and as soon as you can see on which side the opening is, you will tell the experimenter (left, right, top, bottom) and you will look for the next circle. Pay as much attention to this task as you would normally attend to the road ahead and other traffic when driving on a highway.

Imagine during the experiment that a slow car is driving in front of you and you would like to overtake that car. During the experiment a car will approach from behind. Your task is to indicate until which moment you could still move safely and decently to the left in front of the car coming from behind, taking into account the distance and speed difference. For this purpose you can use the buttons to the left side of the steering wheel: You will press the green button as long as you think you can still safely and decently move to the left in front of the approaching car. As soon as you think this is no longer the case press the red button.

After you indicated the 'last safe gap', the field of view through left window in blocked by a curtain. After a while the curtain is dropped. At this moment you will have to make sure whether or not you can move to the left. For this purpose you may look in the driver's side mirror and you may look over your shoulder (act just like you would normally check whether you can move to the left). Again you can give a response using the buttons to the left side of the steering wheel. If there is no other car in the left lane, press the white button. In case there is another car in the left lane, however you can still just move to the left, press the green button (because for this part of the experiment both cars will be driving at the same speed, a small distance between your car and the other car will suffice to move in front of the other car). In case another car is present preventing you from moving to the left, you will press the red button (so in case you would move to the left, you would hit the other car).

In summary:

1. Look ahead to the circles on the road and tell the experimenter on which side the openings are,
2. Press the green button and switch to the red button at the moment you think you can no longer safely and decently move to the left, taking into account the distance and speed difference,
3. As soon as the curtain is dropped, swiftly and accurately indicate whether there is another car in the left lane and whether you can move to the left.

Green button	=	there is another car present, but I can move to the left
Red button	=	there is another car present and I can not move to the left
White button	=	no other car present

APPENDIX E: **Informed consent agreement field experiment (Translation in English; original version in Dutch)**

INFORMED CONSENT AGREEMENT

I,

Name: ....
Address: ....
Date of birth: ....
In the possession of a driver's license: A B C D E (please circle)
Driving experience: .... years , ... kilometer per year

declare to voluntarily participate in an experiment with a test vehicle.

I understand that during the experiment I will have to detect circles on the road and that I will have to indicate whether it is possible to move to the left.

I understand that the runs will be made with a speed of 30 km/h at a closed road in the Flevopolder. During a part of the run the field of view through the left window will be blocked by a curtain.

I understand that an experimenter and a technician will supervise the experiment. The experimenter will provide me with specific instructions concerning the procedure of the experiment. Furthermore the experimenter will operate the measurement equipment in the car and the experimenter will ensure that no inadvertent safety risks are taken.

I understand that at no time I will be asked to perform any unsafe driving actions.

I understand that at no time I will be asked to disobey any traffic laws.

During the experiment, I will be subject to all risks that are normally present while driving a passenger car. The fact that I can not use the inner mirror simulates the situation when transporting a tall load in the back of the car.

I understand that the results of this study will be used for research concerning perception in traffic.

The purpose and procedure of the experiment were satisfactory explained, and possible questions were answered by the experimenter. I will participate on a fully voluntary basis. I was assured that I can, at any moment without giving any explanation, withdraw from the experiment, without any penalty. At the same conditions the experimenter may end the experiment. If the experiment is broken off, regardless the reason, I will be paid the normal fee of DFL 125,-.

For participating in the experiment I will be paid DFL 125,-. The experiment will take approximately 8 hours.

I understand that TNO is investigating perception in traffic and that my performance is not tested as such.

In the report on the results my privacy will be protected. My identity will not be traceable.

Furthermore I declare to be physically fit. I am not under the influence of alcohol, drugs or other substances that impair my ability to drive. I do possess a valid driver's license.

I have read and understand the terms of this agreement. I voluntarily consent to participate.

Soesterberg, ...   (date)

Signature participant: Signature experimenter:

Participant number: