4. Theoretical framework to identify needs for support

The aim of this chapter is to identify those driver tasks for which assistance is most desirable from a road safety point of view. It is assumed that the most promising assistive devices in this respect are those that support the relative weaknesses of the older driver. To identify the strengths and weaknesses of the older driver, a literature review was conducted. Various theoretical perspectives were examined, among which the human factors approach, cognitive psychology, and game theory. This resulted in a list of the relative weaknesses of the older driver and the difficulties that older drivers encounter in traffic as a result of these weaknesses. To be able to rate the relevance of the weaknesses to road safety, the weaknesses were then compared with crash data. Those weaknesses that have a substantial influence on road safety, as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed, were considered to indicate a need for support.

It turned out that these weaknesses are: 1) reduced motion perception and contrast sensitivity, 2) restricted peripheral vision in combination with reduced neck flexibility, 3) reduced selective attention, and 4) reduced speed of processing information and decision making, reduced divided attention, and reduced performance under pressure of time. Based on the difficulties that older drivers encounter in traffic as a result of these weaknesses, a shortlist was composed of desired types of support. It is concluded that to improve the older driver’s safe mobility, assistive devices should a) draw attention to approaching traffic, b) signal road users located in the driver’s blind spot, c) assist the driver in directing his attention to relevant information, and/or d) provide prior knowledge on the next traffic situation.

4.1. Introduction

The aim of this chapter is to identify the driver tasks for which assistance is most desirable from a road safety point of view. It is assumed that the most promising assistive devices in this respect are those that support the relative weaknesses of the older driver. To identify the strengths and weaknesses of the older driver, a literature review is conducted. Various theoretical perspectives are examined, among which the human factors approach, cognitive psychology, and game theory (Sections 4.2 to 4.5). This results in a list of the relative weaknesses of the older driver and the difficulties that

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4 This chapter was based on chapters 2 and 3 of SWOV report R-2003-30 (Davidse, 2004a). Various parts of this chapter were published in IATSS Research, 30(1), 6-20 (Davidse, 2006), and presented at the first HUMANIST conference on driver needs (Davidse, 2004b), and at the International Conference on Transport and Traffic Psychology ICTTP in Nottingham (UK) (Davidse, 2004c).
older drivers encounter in traffic as a result of these weaknesses (Section 4.6). To be able to rate the relevance of the weaknesses to road safety, the weaknesses are then compared with crash data. Those weaknesses that have a substantial influence on road safety – as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed – are considered to indicate a need for support. The result is a shortlist of desired types of support.

The theoretical framework that is used to identify the relative weaknesses of the older driver includes Fuller’s task-capability interface model (Section 4.2), the human factors approach (Section 4.3), cognitive psychological models (Section 4.4), and game theory (Section 4.5). In the next sections, the main emphasis of each of these theories will be described, together with their “opinions” about the strengths and weaknesses of the older driver. While reading these sections, it should be kept in mind that these models and theories are used as a source of information as to what older people are relatively good and poor at (relatively poor can be interpreted as “worse than average”, or “a higher chance of being one of the causes of crash occurrence”) and not to test a hypothesis about some relationship. Therefore, the term ‘framework’ will be used instead of the terms ‘model’ and ‘theory’. The reason for choosing these frameworks and not other ones, or not just one framework, is that the chosen frameworks are all considered to be relevant for describing traffic behaviour and, more importantly, because they are complementary. The latter will be shown in the next section, while describing Fuller’s framework.

4.2. Fuller’s task-capability interface model

4.2.1. A description of Fuller’s conceptual framework

The task-capability interface model of Fuller is a framework that brings together the capabilities of the road user and the demands of the road environment (Fuller, 2000, 2001, 2005). The factors that determine the capabilities of the road user are depicted at the upper left of Figure 4.1, whereas the factors that determine the task demands of the road environment are depicted on the bottom right. The boxes that represent the driver component start off with the constitutional features of the individual, which include the mental and physical characteristics that can be affected by the process of ageing (e.g., reduced visual capabilities, increased perception-reaction time, reduced neck motion). Depending on the nature of the
characteristic, these constitutional features can improve competence, but in case of mental or physical impairments they will generally deteriorate driving competence. Driving competence emerges from training, education and experience. Fuller (2000) refers to competence as the driver’s attainment in the range of skills broadly described as roadcraft, a concept which includes control skills, ability to read the road (hazard detection and recognition), and anticipatory and defensive driving skills.

A driver’s actual (momentary) capability is not necessarily equal to his or her competence. Competence sets a limit on capability. However, capability may be further challenged by a range of variables which are collectively called human factors. These include fatigue, emotions, alcohol and other drugs, stress, distraction and level of motivation to perform the driving task optimally (Fuller, 2000). These human factors can be variable or temporary, whereas constitutional features are more or less fixed. The latter will only change as a result of disorders, diseases or age-related functional limitations.

The task demand of the traffic situation at hand is determined by the environment (i.e., road design, weather conditions, presence of buildings and/or trees), the vehicle one is driving in, driving speed, and the presence and behaviour of other road users. An example of an environmental element that can influence task demands are skew intersection angles; they reduce the
time available for the driver to look, to interpret, to decide and to initiate the appropriate action. Other examples are weather conditions like fog and heavy rain that reduce visibility, and fellow road users that exert pressure to drive faster.

The most interesting feature of Fuller’s framework is the concept of task difficulty. This concept is not explicitly shown in Figure 4.1, but is defined as the result of a confrontation of capabilities (C) and task demands (D). If the capabilities of the road user are higher than the task demands (C > D), the task will be easy and the driver will be in command of the situation. However, if capabilities are lower than task demands (C < D), the task will be too difficult and loss of control will occur (Fuller, 2000).

Another valuable feature of Fuller’s framework is that it integrates the cognitive, motivational and social factors, the vehicle and environmental factors, and the human factors into one conceptual framework. As a result, Fuller’s framework provides various leads for measures that may lower task difficulty. First of all, the driver has several opportunities to keep or regain control (i.e., to lower task difficulty): by lowering his driving speed, changing his road position or trajectory, by choosing an easier route or better driving conditions (e.g., clear weather, daytime), or by communicating with other drivers. The latter strategy will be discussed in more detail in Section 4.5, while describing the framework of game theory. Task difficulty can also be reduced by improving driving skills, for example through professional (re)training. Retraining can be aimed at improving bad driving habits, but it can also be aimed at improving useful field of view, or compensating for functional limitations such as visual deficits (see e.g., Ball & Rebok, 1994; Coeckelbergh, 2001). Another way of lowering task difficulty is by lowering task demands. The human-factors approach (see Section 4.3) is an excellent example of this strategy. The most obvious way of lowering task demands is by adjusting the road environment. However, vehicle adjustments such as the introduction of in-vehicle driver assistance systems can also lower task demands. Driver assistance systems can make the driving task easier by taking over parts of the driving task, such as navigation, lane keeping, or choosing the appropriate driving speed, or by improving capabilities in the sensory domain. Finally, if all this does not work in a particular situation and task demands are higher than the driver’s momentary capabilities, other road users can intervene by taking compensatory actions, such as getting out of the way, thereby avoiding a collision.
4.2.2. Strengths and weaknesses of older drivers according to Fuller’s framework

According to Fuller’s task-capability interface model, the strength of humans is implied in their competences and momentary capabilities, and in the way they cope with discrepancies between their momentary capabilities and task demands. The better a driver copes with the latter discrepancies (by communicating with other road users, adjusting his position on the road and/or his speed), the more he is in control of his weaknesses. These weaknesses are the result of his mental and physical condition, and of variable human factors such as fatigue, emotions, alcohol and other drugs, stress, distraction and motivation.

Looking at the older driver, the abovementioned strengths and weaknesses of the average driver should be supplemented with the mental and physical condition that generally deteriorates as people age (Chapter 2). On the other hand, older drivers usually have a great deal of driving experience. This experience enables them to anticipate the situations they will encounter. Knowing beforehand what will happen will give them extra time to think and act, thereby (partly) compensating for possible mental and/or physical degeneration. It should be mentioned, however, that driving experience might get outdated. If so, it will not give accurate information on how to act in a certain situation anymore.

Another difference between the older adult and the average, somewhat younger driver, is that the older driver is better able to arm himself against the human factors that might influence his momentary capabilities. A first argument in favour of this is that older adults usually have a lower need for sensation seeking (Zuckerman, 1994). As a result, they will be less prone to manoeuvre themselves into risky (traffic) situations. Several studies have shown that older drivers indeed drive less often under the influence of alcohol than younger drivers do and that older drivers more often comply with traffic rules (Davidse, 2000; Hakamies-Blomqvist, 1994c). Furthermore, older adults might profit from the fact that they have more difficulties sharing their attention between various tasks. Having more difficulties sharing attention, they will be less inclined to combine driving with other not driving related activities such as worrying about problems at work, listening to or operating a radio or CD player, and having a (telephone) conversation (Brouwer, Rothengatter & Van Wolffelaar, 1992).
4.3.1. Most important lessons from Fuller’s framework

One can conclude from Fuller’s task-capability interface model that adjustments to the infrastructure and driver assistance systems can make the task of driving easier if they allow for the reduced capabilities of the older driver. If task demands are lowered, the older driver will still be in command of the situation, despite his reduced capabilities. These reduced momentary capabilities are primarily the result of his mental and physical condition.

The other theoretical perspectives that are included in the theoretical framework that is used in this thesis to identify the relative weaknesses of the older driver each focus on a different part of Figure 4.1. The human factors approach shows what the mental and physical capabilities of (older) people are, and how designers of roads, vehicles, and ADAS should take these (limited) capabilities into account. Cognitive psychology focuses on how people deal with differences between capabilities and task demands (“how can we make life easier?”). Game theory, the fourth theoretical perspective, focuses on how people anticipate the actions of others (communication).

4.3. Human factors approach

4.3.1. A brief description of the human factors approach

The human factors approach looks at the boundaries of human information acquisition and processing (see e.g., Sanders & McCormick, 1987; Wickens & Hollands, 2000). It focuses on human beings and argues that the machine (or task) should be designed to fit the human instead of the other way round. The most important cause of human errors according to this approach is that the demands of the system are not geared to the abilities of human beings. In order to prevent errors, designers of a task or system should allow for the physical and mental characteristics of people. In the tradition of the human factors approach, these characteristics are deduced from studies of the boundaries of sensory information acquisition, and the maximum amount of information which can be processed or remembered. A famous example is the finding that the maximum number of items that can be stored in short-term memory is equal to 7 ± 2, thus between 5 and 9 items (Miller, 1956; Sanders & McCormick, 1987: p. 62).
4.3.2. **Strengths and weaknesses of older drivers according to the Human Factors approach**

The most natural way of describing the strengths and weaknesses of older drivers from the perspective of the Human Factors approach is by looking at the various components of human information processing. As people age, information processing capacities generally decline. It should be kept in mind, however, that the age at which declines start as well as the rate at which these declines continue differ from person to person. *Chapter 2* gives a complete overview of the declines relevant for driving. A shorter version is included below.

The aspects of information processing that decline as people age are vision and perception, hearing, selective and divided attention, speed of information processing, muscle strength, and manual dexterity. Visual functions that decrease as people age are visual acuity, peripheral vision, visual acuity in poor light and darkness adaptation, contrast sensitivity, detection of movement, and colour vision (for a detailed description see Klein, 1991; Shinar, & Schieber, 1991; Sivak et al., 1995). It is evident that good vision is very important for safe driving. Motion perception, for example, is important for being able to detect vehicles driving on a crossing road and to estimate their speed, but it is also needed for being able to detect changes in the speed of vehicles straight ahead, that is, stopping, slowing down, speeding up, and reversing (Holland, 2001; Shinar & Schieber, 1991). For car drivers, hearing is perhaps not as critical a sense as vision, but it is potentially an important component of safe driving. As drivers age, they become less able to hear the higher frequencies which provide directional cues, and spatial sensitivity to sound is impaired as a result (Arnold, & Lang, 1995; Maycock, 1997). At the same time, it becomes more difficult for the older driver to filter out unwanted noises (Maycock, 1997).

The abovementioned age-related declines in sensory abilities have an impact on the input the driver receives from other road users and the infrastructure, but also from in-car driver assistance systems. Perceptual and cognitive processes are needed to select the appropriate information, interpret it, and make decisions which must then be translated into an appropriate driving action. Some of these processes decline as people grow older, including the ability to maintain vigilance, selective and divided attention, short-term memory, and information-processing speed (Brouwer, Waterink, Van...
Physical abilities that decline as people age are reduced joint flexibility, reduced muscular strength, and reduced manual dexterity. These age-related changes can influence the ability to get in and out of a car, operate the vehicle, and can influence injury and recovery (Sivak et al., 1995). A reduction in manual dexterity can also interfere with programming in-car driver assistance systems that require coordinated finger movements (Eby, 1999).

4.3.3. Most important lessons from the Human Factors approach

The Human Factors approach tells us that several sensory, cognitive, and physical abilities decline as people age. However, the age at which declines start as well as the rate at which these declines continue differ from person to person. Adjustments to road design and in-car driver assistance systems can meet a need if they help the older driver to observe his environment. These assistive devices themselves should, however, also take the older driver’s declined sensory abilities into account (e.g., contrasts used on roads and traffic signs, design of human-machine interfaces).

4.4. Cognitive psychological frameworks

4.4.1. A description of several cognitive psychological frameworks

Cognitive psychology goes one step further into the minds of people than the Human Factors approach. Whereas the latter approach focuses on the human being and his physical and mental characteristics, cognitive psychology stresses that people interpret the information they receive, and that their actions are almost always aimed at reaching explicit or implicit goals. As a result, the cognitive approach is especially suitable for analysing higher order functions such as problem solving, and decision making. Two theoretical frameworks that originate from cognitive psychology and are frequently mentioned in the literature on road user behaviour are Rasmussen’s skill-rule-knowledge framework (1986), and the hierarchical structure of the driving task as described by Michon (1971). Both frameworks are described below. A third framework that is discussed below is that of situation awareness. The concept of situation awareness focuses on the mental picture that people have of the situation they find themselves in and
how this picture can be distorted or improved by internal and external factors (see e.g., Endsley & Garland, 2000).

Rasmussen’s skill-rule-knowledge framework
Rasmussen (1986) describes human behaviour by the extent to which the individual exerts conscious control on his actions. He distinguishes three types of behaviour which correspond to decreasing levels of familiarity with the environment or task (Reason, 1990). As familiarity decreases, the level of control shifts from skill-based to knowledge-based. The knowledge-based level comes into play in novel situations or when carrying out tasks for the very first time. The rules to play have to be determined, using conscious analytical processes and stored knowledge. This requires much mental effort. For those tasks for which rules are at hand but have not been used much, people function at the rule-based level. At this level, the available rules are consciously acted upon one by one. At the skill-based level, actions have become routines which consist of well-practised procedures. These procedures only have to be triggered and will then run automatically. Whereas task performance at the knowledge-based level is driven by goals, task performance at the skill-based level is triggered by sensory information.

Hierarchic structure of the driving task
Michon (1971; 1985) distinguishes three subtasks in driving: tasks on the strategic, tactic, and operational level. On the strategical level, the driver takes decisions about the route to take, the vehicle to use, and the time of departure. On the tactical level, the driver takes decisions about driving speed, whether it is safe to overtake or join traffic, and how to handle specific traffic situations such as crossing an intersection or passing road-works. On the operational level, the driver takes decisions that relate to vehicle control (i.e., steering, braking, and changing gears). These three levels are hierarchic in the sense that decisions that are made on the strategical level determine what has to be done on the tactical level, and that decisions that are made on the tactical level determine the activities on the operational level. However, the levels also differ in a temporal way. The activities that have to be carried out on the strategical level take the longest time (a few minutes or longer), but can usually be made without time pressure. Activities on the tactical level only last a few seconds, and slight time pressure is usually present on this level. Finally, activities on the operational level take less than a second and the task exerts a constant time pressure, as the driver has only limited time for avoiding or dealing with dangerous situations (Brouwer, 2002a; Hale, Stoop, & Hommels, 1990). Decisions on higher levels can either increase or decrease the probability of running into time pressure on the
lower levels. Time pressure on the operational level can be reduced, for example, by keeping more distance to the vehicle in front (tactical level), or by travelling at less busy times of the day (strategical level).

In Table 4.1, the two hierarchical frameworks of Rasmussen and Michon are integrated into one matrix of tasks. The columns represent the different task levels of driving behaviour, and the rows represent the different levels of attentional control. The grey cells describe the tasks of the experienced driver, whereas the white cells describe those of the novice driver (Hale et al., 1990). Operational tasks are relatively soon operated at a skill-based level. Strategical tasks that relate to an unfamiliar situation require knowledge-based behaviour, even by experienced drivers.

<table>
<thead>
<tr>
<th></th>
<th>Strategic/Planning</th>
<th>Tactical/Manoeuvre</th>
<th>Operational/Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Navigating in a strange town</td>
<td>Controlling a skid on icy roads</td>
<td>Learner on first lesson</td>
</tr>
<tr>
<td>Rule</td>
<td>Choosing between familiar routes</td>
<td>Passing other cars</td>
<td>Driving an unfamiliar car</td>
</tr>
<tr>
<td>Skill</td>
<td>Travelling from home to work</td>
<td>Negotiating familiar intersections</td>
<td>Vehicle handling in bends</td>
</tr>
</tbody>
</table>

Table 4.1. Examples of driving tasks classified according to Michon’s hierarchical structure of the driving task and Rasmussen’s skill-rule-knowledge framework (Adapted from Hale, Stoop, & Hommels, 1990: p. 1383).

**Situation awareness**

Situation awareness (SA) is about maintaining an accurate dynamic picture of the situation, for example, while driving a car. It is about “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988, p. 97; cited in Endsley, 2000). This definition from Endsley already indicates that there are three levels of SA. The first level of SA is the level of perception of important information. At the second level of SA, people combine, interpret, store, and retain the collected information. Multiple pieces of information are integrated and their relevance to personal goals is determined (e.g., crossing an intersection). At the highest level of SA, information about the present situation is used to predict future events (level 3 SA). This ability to anticipate future events and their implications allows for timely decision making, and characterizes the skilled expert (Endsley, 2000). Several factors can influence the accuracy and completeness of a
person’s SA, including attention, goals, stress, workload, expectations, and mental models (see Section 4.4.2).

4.4.2. Strengths and weaknesses of older drivers according to cognitive psychological frameworks

It is much more difficult to point to the weaknesses of the older adult using cognitive psychological frameworks than it is using the Human Factors approach. In fact, the cognitive psychological frameworks of Rasmussen and Michon focus more on the strengths of drivers. According to these models, something inside human beings makes them good at reducing workload and reducing the probability of errors. However, this does not mean that people do this consciously.

According to Rasmussen’s skill-rule-knowledge framework

According to Rasmussen’s framework, one of the strengths of human beings is that they can keep (mental) workload under control by minimizing the mental effort needed for task performance. Human beings are able to do so because they can automate familiar tasks, which results in practically unconscious performance. Humans are perhaps at their weakest during knowledge-based task performance. Hale et al. (1990) hypothesize that drivers at rule- or skill-based level operate more homogeneously and predictably than those at a knowledge-base level. In a traffic environment in which people have to interact with others, unpredictable behaviour may lead to collisions. Assuming that this is correct, designers should try to prevent that people have to operate at the knowledge-based level. This means that they should pay particular attention to the rules which have to be used when abnormal situations occur, for example when road maintenance has to be carried out. As much as possible, drivers should be able to rely on common routines. If this cannot be guaranteed, the deviation must be signalled as dramatically as possible in order to break into the routine.

Although task performance at the skill-based and rule-based level is more predictable, it is not free from failures. Errors that are made at these levels of task performance are, however, relatively less frequent and easier to prevent. Errors at the skill-based level are called slips (and lapses). They are the result of correct intentions but incorrect actions. One knows what has to be done but the actual implementation is wrong. The latter being the result of inattention or overattention. No or too much attention is paid to the routine action one is carrying out (see e.g., Reason, 1990). Errors in rule- and knowledge-based behaviour occur during problem-solving activities, leading
to incorrect intentions as well as incorrect actions. These types of errors are called mistakes. At the rule-based level, incorrect intentions can be caused by a wrong diagnosis which leads to the misapplication of good rules or the application of bad rules. An example of a wrong diagnosis is a tendency to overuse diagnoses that proved to be successful in the past. The accuracy/correctness of such a successful diagnosis will be tested first regardless of whether it is actually applicable to the current situation (for other examples of rule-based mistakes see Reason, 1990). At the knowledge-based level, incorrect intentions can occur as a result of insufficient knowledge and/or pressure of time. Situations in which both factors are represented can lead to various types of errors. An important source of these errors lies in selective processing of task information. Mistakes will occur if attention is given to the wrong features or not given to the right features (for more information about these and other examples of knowledge-based mistakes see Reason, 1990).

**According to the hierarchic structure of the driving task**

According to Michon’s hierarchic structure of the driving task, one of the strengths of human beings is that they can keep (mental) workload under control by reducing time pressure. On the operational level, pressure of time is high, especially if one needs more time to decide as a result of declines in sensory abilities and/or decreased information processing capacities. This time pressure can be reduced by decisions on the higher levels. On the tactical level, the driver can decide to keep more distance to the vehicle in front in order to have more time to react. Another decision that can be made on the tactical level is to reduce speed well before approaching an (unfamiliar) intersection in order to have more time to perceive all aspects of the traffic situation, to interpret them and to decide on how to act. On the strategical level, the driver can decide to take the route with traffic lights instead of the one with signs which force him to decide for himself when it will be safe to cross traffic streams. In addition, he can decide to drive during daytime, thereby avoiding difficulties as a result of night-time visual acuity and sensitivity to glare.

One can think of various reasons why older people in particular have the possibility to compensate (Brouwer & Davidse, 2002; Brouwer, Rothengatter & Van Wolffelaar, 1988). In the first place, they often have more freedom in choosing when to travel. Various studies have shown that older adults more often choose to drive during daytime and dry weather (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1994c; McGwin & Brown, 1999;
Smiley, 2004; Zhang et al., 1998). In the second place older people on average have a great deal of driving experience. The traffic insight they have acquired may give them the ability to anticipate on possible problematic situations. In the third place, the diminishing desire for excitement and sensation when getting older possibly might play a role. Older people, on average, less often drink-drive than younger adults and are generally more inclined to obey the traffic rules (Brouwer, Rothengatter & Van Wolffelaar, 1988; Hakamies-Blomqvist, 1994c).

According to the concept of situation awareness

The theoretical basis of the concept of situation awareness is for a large part extracted from the fields of ergonomics and cognitive psychology. As a result, the relative weaknesses of human beings in the area of perception and cognitive abilities according to the concept of situation awareness are the same as those which were identified in the previous sections. This section describes what the effects of these weaknesses are on the acquisition of situation awareness.

For obtaining level 1 SA (perception) it is important that relevant information can be perceived optimally. Factors which may disturb optimal perception are bad visibility (e.g., fog), functional limitations in the area of perception, and attentional deficits, either caused by distraction or reduced selective and/or divided attention. In their study on the causes of pilot errors, Jones & Endsley (1996; cited in Endsley, 2000) found that 76% of all errors had its origin in problems in the perception of needed information. As a result, this first phase of obtaining SA appears to be the weakest link in obtaining good situation awareness.

One of the strengths of humans is, according to the concept of situation awareness, their use of mental models. These models are the result of experience. Experienced drivers have developed mental models of the vehicle they use and the traffic system they are driving in (i.e., road network, traffic rules, traffic participants). These models include schemata which describe prototypical situations. If a real-world situation matches a prototypical situation, the meaning of the real world situation will quickly be clear to the driver. This will assist in obtaining level 2 SA (comprehension) as well as level 3 SA (projection). Mental models and the schemata associated with them also assist the experienced driver with obtaining level 1 SA (perception): they direct the driver’s limited attention to relevant aspects of the situation.
Stating that experienced drivers can maintain their SA more efficiently than inexperienced drivers does not mean that an experienced driver will always have better SA. Experience can also have an adverse effect on SA. An experienced driver who relies too much on mental schemata to select and interpret information may misinterpret an unexpected situation or not even notice it (Endsley, 2000; Wickens, 2001). These errors match the ones that were discussed in the section on strengths and weaknesses according to Rasmussen’s skill-rule-knowledge framework: as a result of habit formation, routine actions are also carried out in situations in which they are not appropriate, or changes in the situation at hand are not noticed. In cognitive psychology, such adverse effects of experience are known as negative transfer and attentional narrowing (see e.g., Johnson & Proctor, 2004; Wickens & Hollands, 2000).

Bolstad and Hess (2000) have examined the effects of age-related cognitive changes on the acquisition of SA. For each of the levels of SA, they have studied the effects of general slowing, decreasing processing resources, and inhibition. In addition, they have examined whether experience can compensate for any negative effects of ageing on SA. The results of Bolstad and Hess’s exercise are summarised below. Note that, although Bolstad and Hess focus on the cognitive aspects of ageing, they point out that changes in sensory functions affect the acquisition of SA as well.

Age-related declines in selective and divided attention may influence the acquisition of level 1 SA through the reduced efficiency with which older people search the environment for relevant information, and the extent to which they can pay attention to different sources of information or perform more than one task at the same time. Both cognitive changes may have a negative effect on the quality and quantity of the information that people will have at their disposal. Selective attention appears to be particularly affected by ageing when the individual must search the environment for relevant information or when target information competes with other information in the environment. The impact of some attentional deficits can probably be made smaller with appropriate environmental supports to guide processing. Another way of guidance is provided by the mental models and schemata which were discussed earlier: they will also direct the driver’s limited attention to relevant aspects of the situation. Apart from declines in selective and divided attention, cognitive slowing may also have a negative effect on the acquisition of level 1 SA. This may particularly be the case in complex
situations where cues in the environment are changing at a relatively rapid, externally paced rate, straining older adults’ capabilities to keep pace with the information flow (Bolstad & Hess, 2000).

The acquisition of level 2 SA, integration of selected information and existing knowledge in order to form a coherent and useful picture of the situation, is of course strongly dependent on the information that was selected in Stage 1 and has been stored in memory. Due to age-related cognitive changes, individuals may have either selected inappropriate information or been unable to select the appropriate information, thus affecting the nature of the information available to the individual. In addition, age-related difficulties in retrieving and utilizing information registered during Stage 1 may affect the creation of an accurate mental model.

For level 3 SA, the effect of cognitive changes is probably the largest in those situations in which it is not possible to fall back on existing knowledge and experience. When such knowledge is not available, and inferences that are necessary for future projections must take place in a more bottom-up fashion, age differences might be more prevalent due to the increased demands on working memory processes. In addition, it should be noted that the projection accuracy is only as good as the information which is used in that process. A low level 1 SA and level 2 SA will restrict the acquisition of level 3 SA.

4.4.3. Most important lessons from cognitive psychology

One can conclude that cognitive psychology offers several clues as to how the boundaries of human information processing can be compensated for. Not only by drivers themselves, but also by road authorities. Examples of compensatory actions that drivers can take are travelling at particular times, following a particular route, and/or driving at a lower speed. Another thing that cognitive psychology tells us is that driving experience (and other kinds of experiences) results in mental models that help the driver in choosing the action that is appropriate for the situation he is in. Elements of the traffic situation trigger the appropriate action without the driver having to take into consideration every possible action (see for example Wickens and Hollands, 2000). Designers should be aware of these mental models and the way they are triggered. If a (new) situation looks similar to a well-known situation but in fact is completely different and also requires different actions, mental models will work counterproductive. Therefore, mental models should be
taken into account by road designers and designers of ADAS and their human machine interface.

4.5. Game theory

4.5.1. An introduction to game theory

Game theory is about decision making and anticipating the likely reaction of others (Von Neuman & Morgenstern, 1944). A famous example that originates from this theory is the so-called prisoner’s dilemma in which suspects of a crime have to decide whether they should talk or remain silent about the other’s contribution to the crime committed. The combination of their decisions (talk or remain silent) determines the length of their imprisonment. People who are involved in a game like this often have conflicting interests and attempt to prevail their interest over those of the others. To achieve that goal, they need information about the motives and intentions of the other ones involved. However, information is often not available. As a result, people base their decisions on the likely reaction of others.

A type of game that applies to traffic behaviour is the so-called Chicken game. Oye (1985) describes this game using the situation in which two drivers meet each other on a narrow road. If one of the drivers makes room for the other, he could be regarded as the ‘chicken’ whereas the other one may call himself the ‘hero’. If neither of them is willing to make room, both drivers may suffer from damage to their car. If both drivers decide to make some room, loss of reputation will be minimized for both drivers.

Several factors can influence the outcome of a game. One factor that is described in literature is an existing balance of power. In the prisoner’s dilemma, for example, one of the prisoners may hold a higher rank in the criminal organisation they both belong to. In traffic, differences in power can result from traffic rules (e.g., right of way), the type of vehicle people drive, or the type of road they are driving on. A second factor that may influence the outcome of a game is the extent to which ‘players’ can view the behaviour of the other(s) involved. Being visible to the other ‘players’ of the game may give people the opportunity to influence their behaviour. For example, drivers may approach an intersection at high speed, thereby enforcing right of way. A third factor is the willingness to cooperate. According to Oye (1985), this willingness depends on: 1) the value which
players attach to the outcome of the game, 2) how many times the game is or will be played, and 3) the number of players involved. In traffic, the first factor is probably determined to a large extent by the desired driving speed, driving style, and state of mind (e.g., relaxed, in a hurry, irritated, tired). The number of times the game is played may influence the willingness to cooperate through the principle of tit for tat: if I have made room for another driver twice, I will not do it for the third time. The number of players that is involved in the game predominantly influences the complexity of the comparative assessment the drivers have to make.

4.5.2. **Strengths and weaknesses of older drivers according to game theory**

The traffic situation which was described in the previous section clearly explains the principles of game theory. However, it is not very useful for a description of the strengths and weaknesses of the older driver, especially if its purpose is to identify needs for support. After all, crashes on narrow roads which are caused by drivers who are not willing to make room for each other are not very common among older drivers. A traffic situation that applies more to the difficulties older drivers encounter in traffic is one in which several road users approach the same intersection and have to decide in which order they will cross the intersection. This situation will be used to identify the strengths and weaknesses of older people as they interact with others (see Heijer & Wiersma (2001) for a similar approach).

When approaching a major road, each of the road users will look around to see which other road users have arrived at the intersection at the same time, how they behave, in what way they pose a threat (i.e., mass and speed of their vehicle), and who has priority according to the traffic rules. Based on this information, the road users will work out who will be the first one to cross the intersection, who will be next, and when it will be their turn. For a safe transaction it is important that every road user can see all the other road users and that everyone knows what is expected of him. These preconditions will not always be satisfied. Age-related functional limitations such as declines in selective and divided attention, and reduced detection of movement may make it more difficult for older drivers to observe and interpret the behaviour of other road users. They may compensate for these limitations by approaching the intersection at a lower speed, which will give them more time to view the others and decide what to do. Fellow road users may very well misinterpret this behaviour. They may think the older driver is being polite or is just complying with the traffic rules and expect that he
will therefore yield to them. As a result, they will be completely unprepared to start avoidance manoeuvres if the older driver nevertheless suddenly accelerates into the intersection area. Several examples of similar suboptimal communication between young and older drivers have been reported in studies of naturalistic driving situations: older drivers more often drove with an irregular and hesitant pace, they communicated less with other participants and were less often the first person to resolve a traffic conflict (Brendemühl, Schmidt & Schenk, 1988; Risser et al., 1988; cited in Brouwer & Ponds, 1994).

Although road users may not always understand each other, communication between road users still appears to be one of the reasons why the number of crashes in traffic is relatively low if compared with the general error rate for routine operations where care is required (Heijer & Wiersma, 2001). Therefore, if assistive devices are introduced to improve the safety of the (older) driver, they should not interfere with the natural communication between road users. In-car driver assistance systems often aim solely at the correction of errors of the users. This disregards both the error-compensating capacities of surrounding traffic and the possibilities to compensate for failures of others, which is not only inefficient but can also be dangerous because the actions of the assistance system may disturb these error-correcting processes (see also Section 7.3.5).

4.5.3. Most important lessons from game theory

One can conclude that, from a game theoretical perspective, people are relatively bad at perceiving all the relevant information that is needed to make the right decision. Assistive devices could provide support by giving timely information on who is arriving at the intersection and what is about to happen (including the priority regulation). In addition, they can help in making the right decision based on the available information. However, one important precondition for safe interventions by in-car assistive devices from a game theoretical perspective is that cars that have these devices will have to ‘behave’ the same way as they would have done if they were operated by humans. This means that they should not only take into account what their own “boss” does, but also anticipate actions of others. Otherwise, their behaviour might come across as behaviour of an alien or at least as antisocial behaviour to drivers not having the assistive device, which may result in crashes after all.
4.6. Driver needs

The above theoretical framework provided us with information about the relative weaknesses of the older adult. Note, however, that not every weakness of the driver has negative road safety consequences. After all, many weaknesses can be compensated for. Take for example restricted peripheral vision; that can be compensated for by increased movements of head and neck. Only when a combination of several weaknesses makes it impossible to take compensatory action or to act in the available time period, driving problems will arise. Depending on the circumstances (remember the compensatory action that fellow road users can take) these problems might in the end result in a crash.

We may state that the relative weaknesses of the older driver create an objective need for adjustments to road design and in-car driver assistance systems that offer driver support on these specific areas. This objective need for support can be formulated more precisely by indicating the driving-related difficulties that arise as a result of these weaknesses. By quantifying these difficulties based on how often they result in crashes, we also have a standard that can be used to rank the need for different kinds of support. Table 4.2 shows the results of such an exercise. In horizontal direction, the table successively shows the weaknesses of the older adult, the difficulties he is faced with as a result of these weaknesses (accompanied by the extent to which these problems contribute to the total number of crashes), and the type of support that could prevent such driving-related difficulties. Knowledge of the weaknesses of the older driver is not only of use for the identification of their need for support, but also for the design of assistive devices: how to provide support. The weaknesses that should be taken into account when designing measures concerning the infrastructure and human machine interfaces for driver assistance systems are indicated by “(DESIGN)” in the right-hand column. In vertical direction, the table reflects the stages of information processing.
## Vision and hearing

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Driving related difficulties and their relevance to road safety</th>
<th>Assistance needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral vision</td>
<td>Overlooking other road users while merging or changing lanes (7: ++ OD)</td>
<td>Signal or provide view of objects that are located in the driver’s blind spot</td>
</tr>
<tr>
<td>Night-time visual acuity</td>
<td>Difficulty seeing pedestrians and other objects at night and reading signs (x)</td>
<td>Artificially light objects (other road users and road design elements)</td>
</tr>
<tr>
<td>Sensitivity to glare</td>
<td>Temporary loss of visual information (x)</td>
<td>Prevent glare (DESIGN)</td>
</tr>
<tr>
<td>Contrast sensitivity</td>
<td>Difficulty reading signs and in-car displays and difficulty with depth perception and estimating the speed of other road users (11: + OD)</td>
<td>(DESIGN)</td>
</tr>
<tr>
<td>Colour vision</td>
<td>Difficulty discriminating between similar colours; relevant to reading signs and in-vehicle displays (x)</td>
<td>(DESIGN)</td>
</tr>
<tr>
<td>Motion perception</td>
<td>Difficulty judging the movement of fellow road users and their approach speed (6: ++++)</td>
<td>Draw attention to approaching traffic</td>
</tr>
<tr>
<td>Hearing</td>
<td>Difficulty locating the direction of sounds and ignoring noise (x)</td>
<td>(DESIGN)</td>
</tr>
</tbody>
</table>

### Cognitive processing and decision making

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Driving related difficulties and their relevance to road safety</th>
<th>Assistance needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divided attention</td>
<td>Driving task performance gets worse when other tasks have to be performed simultaneously; see also ‘speed of information processing and decision making’ (x)</td>
<td>(DESIGN)</td>
</tr>
<tr>
<td>Selective attention</td>
<td>Overlooking traffic signs and signals (3: ++)</td>
<td>Assist the driver in directing his attention to relevant information</td>
</tr>
<tr>
<td>Speed of processing information and making decisions</td>
<td>Reaction time increases as the complexity of the traffic situation increases (3: ++)</td>
<td>Provide prior knowledge on the next traffic situation</td>
</tr>
<tr>
<td>Performing tasks consciously</td>
<td>Difficulty driving in an unfamiliar environment (x)</td>
<td>Provide prior knowledge on the next traffic situation</td>
</tr>
</tbody>
</table>

**Table 4.2.** Weaknesses of older adults, driving-related difficulties and assistance needed, prioritized by their relevance to road safety.

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Theoretical framework to identify needs for support

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Driving related difficulties and their relevance to road safety</th>
<th>Assistance needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexibility of head and neck</td>
<td>Overlooking fellow road users when merging or changing lanes (7; ++ OD)</td>
<td>Signal or provide view of objects that are located in the driver’s blind spot</td>
</tr>
<tr>
<td>Manual dexterity and strength</td>
<td>Difficulty programming on instrument panels (x)</td>
<td>(DESIGN)</td>
</tr>
<tr>
<td>Interaction with other road users</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance under pressure of time</td>
<td>Suboptimal decisions (3: ++)</td>
<td>Provide prior knowledge on the next traffic situation</td>
</tr>
<tr>
<td>Insight in the behaviour of other road users</td>
<td>Difficulty predicting the intentions of other road users (14: +)</td>
<td>Draw attention to approaching traffic and its behaviour</td>
</tr>
</tbody>
</table>

1 The text between the brackets refers to the data in Appendix B. The numbers correspond to the numbers preceding the needs for information and/or assistance in the Appendix (first column). The plus signs, "0" and "x", refer to the percentage of the total number of crashes that could be avoided if the need would be met: >10%=+++; 5-10%=++; 2.5-5%=++; < 2.5% = 0; x=no data available (second column of the Appendix). OD (Older Driver) means that one plus sign is added to account for the underestimation of the number of crashes involving older drivers (third column of the Appendix). The most important needs for support are printed in bold. See text for further explanation.

Table 4.2 (continued). Weaknesses of older adults, driving-related difficulties and assistance needed, prioritized by their relevance to road safety.

The relevance of the driving-related difficulties (middle column) to road safety is derived from Malaterre and Fontaine (1993). They have investigated the relation between crash types and the need for information and assistance using in-depth crash data. The percentage of crashes that could be avoided by providing the driver with information that is relevant to a certain driving problem was used as an indicator of the relevance of that driving problem to road safety. In Table 4.2 this relevance is expressed in terms of plus signs; the more plus signs, the more relevant it is to road safety (See Appendix B for the data of Malaterre and Fontaine).

Using the percentages of Malaterre and Fontaine (1993) has the disadvantage of them being based on the total number of crashes and therefore on the “average” road user. Several studies have indicated that older adults are more often involved in crashes while turning left and while merging (Aizenberg & McKenzie, 1997; Davidse, 2000; Hakamies-Blomqvist, 1993, 1994c; McGwin & Brown, 1999; Zhang et al., 1998). In this respect, the
percentages of Malaterre and Fontaine underestimate the relevance to road safety of some of the driving-related difficulties of older adults. In Table 4.2 this is corrected for by giving the relevant difficulties an extra plus sign (and the code OD).

Based on Table 4.2, we can conclude that the most important need for support, from a road safety perspective, stems from the following driving-related difficulties (printed in bold in Table 4.2) and weaknesses that cause them (relevant to 5% or more of the total number of crashes of older drivers):

a) difficulty judging whether fellow road users are moving and at what speed they approach the intersection (motion perception and contrast sensitivity);

b) overlooking other road users while merging and changing lanes (peripheral vision and flexibility of head and neck);

c) overlooking traffic signs and signals (selective attention);

d) reaction time increases as the complexity of the traffic situation increases (speed of processing information and decision making, divided attention, performance under pressure of time).

The right-hand column of Table 4.2 describes the kind of assistance that is needed. These descriptions are simply derived from the driving-related difficulties. Only the type of assistance is mentioned, not the way in which the assistance could be provided or which existing road design elements or driver assistance systems already provide for it. Based on the abovementioned driving-related difficulties, the assistive devices most needed will:

a) draw attention to approaching traffic;

b) signal or provide view of road users located in the driver’s blind spot;

c) assist the driver in directing his attention to relevant information; and/or

d) provide prior knowledge on the next traffic situation.

In addition, while designing measures concerning the infrastructure and human machine interfaces for driver assistance systems, people should take into account the older drivers’ increased sensitivity to glare, and their reduced contrast sensitivity, colour vision, hearing, divided attention and manual dexterity and strength.

Section 5.3 and Chapter 7 discuss assistive devices that already seem to provide the abovementioned types of support, or that may do so in the near
future. Section 5.3 focuses on road design elements that allow for the functional limitations of the older driver, whereas Chapter 7 discusses relevant in-car driver assistance systems and the conditions they should meet to actually improve the safety of older drivers.