2 Self-Explaining Roads

Richard van der Horst & Nico Kaptein

ABSTRACT

As a means to a sustainable safe traffic environment the concept of Self-Explaining Roads (SER) has been developed. The SER concept advocates a traffic environment that elicits safe driving behaviour simply by its design. In order to support safe driving behaviour and appropriate speed choice, drivers should be enabled to recognise the type of road they are on. Therefore, it is important that the way people subjectively categorise these roads matches the function and use of roads. However, most Dutch roads do not display enough structure to allow for an effective utilisation of these SER design principles yet. Several studies indicate that road users are not able to distinguish roads according to official road categories. So far, no studies have explicitly addressed the relationship between cognitive road classification and actual driving behaviour. The present study investigated to what extent cognitive road classification determines driving speed. Both a picture-sorting task and a driving simulator task were used to investigate the effects of design characteristics on cognitive road classification and driving behaviour. In both tasks, three road design conditions were involved: one consisted of a set of Current Roads, roads as they are in reality; one of a set of Self-Explaining Roads; and one of both Current Roads and Self-Explaining Roads. Each of the three different sets of roads consisted of eight exemplars of each of four road categories: motorways, motorroads, 80 km/h roads for fast traffic and 80 km/h roads for mixed traffic.

The picture-sorting task showed that subjects categorised Self-Explaining Roads more in accordance with the official road category system than Current Roads. A more systematic application of road design elements results in a subjective road classification that is more in accordance with the official road category system. Subjects did not only classify on the basis of road characteristics, but they also used the whole set of road environments, the context, they were part of. The driving simulator task showed that driving behaviour on motorroads with a SER design was more in accordance with driving behaviour as meant by the official road design. No clear-cut evidence was found for an effect of cognitive road classification as such on the level of driving speed. Yet, results showed that a more consistent road design within categories may lead to more homogenous driving speeds.

INTRODUCTION

Currently, road design is hardly adapted to human capabilities. The crucial question is how the occurrence of errors in traffic can be reduced. Two aspects have been proposed as important in obtaining a sustainable safe traffic system: Inherent Safety and Self-Explaining Roads (SER). Inherent Safety refers to the reduction of potentially dangerous encounters, whereas Self-Explaining roads are roads with a design that evokes correct expectations from road users (Theeuwes & Godthelp, 1992). Because training and education cannot be expected to dramatically reduce
the number of traffic accidents, it is important that road design in itself elicits safe traffic behaviour.

People structure their world by gaining a maximum of information with as few cognitive efforts as possible (cognitive economy, Rosch, 1978). It is often stated that people perceive objects in the world as correlated and structured, but not all combinations of objects or characteristics of objects can be memorised. Cognitive economy provides an efficient way to deal with the environment one is coping with, without having to store all characteristics of that environment (Twisk, 1991).

There are several models of categorisation. The SER concept holds to a mixed model of categorisation, which is an extension of a prototype model. In prototype models each category is represented by an exemplar that contains the most important characteristics of that category, a prototype (Reed, 1972). Characteristics of newly encountered objects or environments are matched against a representation stored in memory of previous, similar experiences with these objects or environments. Stored representations are conceptualised as schemata and the degree of similarity between a schema and the newly encountered environment indicates how prototypical the latter is (Purcell, 1986). Typical characteristics of these prototypical representations are expected to be more similar within one category than between different categories. As Rosch (1978) states: “To categorise a stimulus means to consider it, for purposes of that categorisation, not only equivalent to other stimuli in the same category but also different from stimuli not in that category”. According to Neisser (1987) and Rips and Collins (1993) similarity alone is not sufficient to explain categorisation. Mixed models use not only prototypical information to categorise but also information about specific experiences or exemplars, rules and theories (cognitive models).

According to the SER concept, road users classify road scenes into categories. Each type of road has its prototypical representation, so separate roads do not have to be stored individually. Prototypical representations of road scenes develop through experience and constitute the basis for categorising road environments (Theeuwes, 1994). As soon as an unknown road is encountered, existing schemes and their typical characteristics are used to categorise this road as a member of a subjective category. In order to obtain Self-Explaining Roads, it is important that the design of the infrastructure is adjusted to the way the road environment is categorised in the ‘heads’ of its users (Theeuwes & Diks, 1995b). This would bring about successful categorisation leading to a timely anticipation of possible events on a road. Inadequate categorisation would induce wrong expectations of events. Wrong expectations lead to perceptual and judgement faults that result in inadequate or missing anticipations. Inadequate or missing anticipations may lead to wrong or improperly performed manoeuvres. Relatively many human failures in traffic have to do with specific manoeuvres, involving passing or crossing other traffic, parking and stopping.

A homogeneous set of road characteristics within one road category and different characteristics between categories, should provide road users with direct information about the type of road they are driving on and about the types of behaviour drivers on that road should adopt. A study by Theeuwes and Diks (1995b) showed that estimated appropriate driving speed is related to the way roads are categorised. Between-subjects comparison showed that subjective categories for a set of road environments
matched classes of estimated driving speed for that same set of road environments. Thus, Self-Explaining road design may facilitate correct anticipation and increase safety (Dijkstra & Twisk, 1991).

In the present situation, road elements that are prototypical for a single road category are hard to find. Roads from each official road category have a wide range of varying characteristics, such as number of lanes or presence of edge lines, which results in a large variety of road scenes per category. Design characteristics that are specifically tied to a certain road category have to be developed in order to facilitate consistent categorisation (Theeuwes & Godthelp, 1992). Several studies have shown that road users are not able to categorise current roads in a meaningful way (Theeuwes & Diks, 1995a, 1995b; Kaptein & Theeuwes, 1996).

So far, no studies have explicitly addressed the relationship between cognitive road classification and actual driving behaviour. The present study investigated to what extent cognitive road classification determines behaviour. To that end, it was investigated to what extent results obtained in a static laboratory setting were informative on dynamic driving behaviour in a driving simulator.

2.1 GENERAL DESIGN

Both a picture-sorting task and a driving simulator task were performed. The picture-sorting task was used to investigate the effect of road characteristics on cognitive road classification. Subjects had to sort computer generated images of road environments of four road categories with respect to the behaviour they would show and expect on these roads. The four road categories form a hierarchy, in which category A is the highest-ranked category and D the lowest-ranked category. The simulator task was used to investigate the effect of road characteristics on driving behaviour. The subjects had to drive in a driving simulator along an indicated route through a road network of computer generated images. Finally, it was investigated whether cognitive road classification affected driving behaviour.

Table I shows the speed limit and the occurrence of possible other traffic for four official categories of roads outside built-up areas in The Netherlands. Note that in the present study the word ‘Motorway’ is used in the sense of the British ‘Motorway’ (American ‘Freeway’), the highest standard of road available, whereas ‘Motorroad’ (‘Autoweg’ in Dutch) refers to a slightly lower order road with at level intersections and an 100 km/h speed limit (single or dual carriageway national main roads).

Table I: Four official categories of road outside the built-up area in The Netherlands. For each category the speed limit and the occurrence of possible other traffic is given.

<table>
<thead>
<tr>
<th>Category</th>
<th>Speed limit</th>
<th>Cyclists</th>
<th>Slow motor vehicles</th>
<th>Oncoming traffic</th>
<th>Crossing traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Motorway</td>
<td>120</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B Motorroad</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>C 80-km/h road for fast traffic</td>
<td>80</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D 80-km/h road for fast + slow</td>
<td>80</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Both tasks (picture sorting and driving simulator) were performed with three road design conditions, each by a different group of subjects. In Condition 1, a group of
sixteen subjects was assigned to a database that contained eight Current Roads per road category (A, B, C, D; see Table I). Typical properties of these roads were that they had relatively little characteristics that overlapped within categories and relatively many that overlapped across categories. This reflects the road network as it is in reality. In Condition 2, a group of sixteen subjects was assigned to a database that contained eight Self-Explaining Roads per road category. Typical properties of these roads were that they had relatively many characteristics that overlapped within categories and only a few across categories. In Condition 3, a group of sixteen subjects was assigned to a database that contained six Current Roads and two Self-Explaining Roads per road category. For both tasks the subject groups from these three conditions were homogeneous with respect to sex, age and driving experience. Different subjects were used for the picture sorting task and the simulator task, to avoid the possibility that performance on one task would influence performance on the other.

The stimuli of the simulator task were represented as computer-generated road environments, constructed as a simulator database. The stimuli for the picture-sorting task were pictures taken from this database (for examples, see Appendix I).

Condition 1 and 2 of the picture sorting task were compared to investigate to what extent proposed design changes for different types of roads lead to a more appropriate cognitive road classification. It was expected that road environments of the ‘Self-Explaining-Road (SER) design’ would be more uniform within one category and more different across categories, and would be more in accordance with the official road categories than road environments of the ‘Current-Road (CR) design’.

Condition 1 and 2 of the driving-simulator task were compared to investigate to what extent proposed design options for different types of roads lead to more appropriate driving behaviour. Speed choice was used as the main dependent variable. If SER design were important for driving speed, it would be expected that road environments of the SER design would elicit driving behaviour that is more uniform within one category and more different across categories than for road environments of the ‘CR design’. Moreover, driving behaviour should be more in accordance with driving behaviour as meant in official road categories.

Condition 2 and 3 of both the picture sorting task and the simulator task were compared to investigate whether cognitive road classification as such had an effect on driving behaviour. If so, it would be expected that the Self-Explaining Roads within the mixed design group of roads would elicit a less efficient categorisation of its users than within a Self-Explaining group of roads. This would elicit different driving behaviour on those, physically identical, roads between the two conditions (Mixed design and SER design). Behaviour on Self-Explaining roads within a group of SER roads is expected to be more in accordance with driving behaviour as intended by the road design, than driving behaviour on Self-Explaining roads within a mixed group of roads.
Table II shows road characteristics of Current roads based on the official guidelines and road characteristics of Self-Explaining roads, based on the SER-concept.

Table II: Road characteristics of the CR design and the SER design, according to the official guidelines and the SER-concept, respectively. Where relevant all measures are in metres.

<table>
<thead>
<tr>
<th></th>
<th>Current Roads</th>
<th>Self-Explaining Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Width of carriageway</td>
<td>8.35/7.95</td>
<td>6.75</td>
</tr>
<tr>
<td>Width of lanes</td>
<td>3.50</td>
<td>3.10</td>
</tr>
<tr>
<td>Edge lines</td>
<td>0.15/0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Recovery lane</td>
<td>1.10/0.60</td>
<td>0.35</td>
</tr>
<tr>
<td>Width of emergency lane</td>
<td>3.50/4.00</td>
<td>-</td>
</tr>
<tr>
<td>Guard rail</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Number of carriage ways</td>
<td>2×2</td>
<td>2×2/1×2</td>
</tr>
<tr>
<td>Centre-line markings; Space in between</td>
<td>0.10/0.15</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>3-9</td>
<td>3-9</td>
</tr>
<tr>
<td>Bicycle lane width</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

To investigate the effects of road design on driving behaviour, the effects of interfering variables had to be excluded. Therefore all road environments fulfilled the following requirements: there was no other traffic visible, there were no traffic signs that could provide information about the official category the road belonged to and there were no sharp curves in the road that could influence driving speed. The CR design reflected the variety of road scenes in reality within each official road category. The road characteristics of the current roads represented in Table II were taken from the design guidelines for motorways and the guidelines for non-motorways (ROA, 1989; 1991; 1992; 1993 and RONA, 1992; 1986; 1986). In order to evaluate the contribution of road elements that are supposed to improve categorisation, the SER design was obtained by selectively and systematically adding or removing road characteristics to or from the database for the current road design. The choice of road characteristics for the SER design systems was based on previous studies on road design and subjective categorisation.

For the SER design all characteristics had been standardised, so that only one value was used for each property dimension within each road category. For example, width of carriageway was varied systematically so that all roads within one road category had the same width. Width was chosen to be systematically smaller for lower order road categories because a smaller carriageway corresponds to a lower driving speed, which better suits a lower order road. Consequently, road width was informative on road category. Similarly, emergency lanes and guard rails (in The Netherlands mainly used on motorways) are typical characteristics of motorways and have a confusing effect when placed on another road category (Theeuwes, 1994).

The number of carriageways has been important for the distinction between road categories (Kaptein & Theeuwes, 1998). As for motorroads, the guidelines for the number of carriageways are ambiguous: both single carriageways (1×2 lanes) and dual carriageways (2×2) exist. To avoid wrong anticipations from the driver as a consequence of this ambiguity, in the SER design a choice had to be made between single and dual carriageways. A dual carriageway motorroad would help to
distinguish between motorroads and 80 km/h roads for fast traffic and a single carriageway motorroad would help to distinguish between motorroads and motorways. It is known from the literature that motorroads and roads for fast traffic are difficult to distinguish and that motorways are easy to be seen as a homogeneous category (Theeuwes & Diks, 1995). Therefore, a dual carriageway was chosen. Space between centre-line markings was varied between roads for fast traffic and other roads to further improve the distinction between motorroads and 80 km/h roads for fast traffic. The choice between a 3-9 and a 9-3 mark-gap ratio had to be made. Normally the 9-3 mark-gap ratio (nine metres of white stripe and three metres of space in between) urges caution, which implies a slower driving speed, and makes it easier to categorise a road as a lower order road. Therefore a 9-3 mark-gap ratio was chosen for the lower order road category, the 80-km/h road for fast traffic.

The absence of centre-line markings makes roads for fast and slow traffic more homogeneous and easier to distinguish from roads for fast traffic (Theeuwes & Diks, 1995b). Red bicycle lanes on roads for fast and slow traffic further stresses this distinction, since the possibility of encountering slow traffic is communicated through road design (Kaptein & Theeuwes, 1996).

2.2 PICTURE SORTING TASK

From each of the four official road categories, 8 different pictures of road environments were selected. A total number of 32 stimuli was used. They represented typical roads for these categories. Each picture was classified according to its corresponding official category as A1 to A8, B1 to B8, C1 to C8 or D1 to D8 (see Appendix I). In the mixed road design condition, for each road category from the CR design two current roads were replaced by their ‘identical’ counterpart from the SER design, viz. A1 and A8, B1 and B2, C4 and C6, and D3 and D4, respectively.

2.2.1 Procedure

For each road design system, a separate group of 16 subjects was used. Each subject had to sort 32 pictures. An overview of this method is given by Rosenberg (1982). One of the main advantages of the sorting method in comparison to judgement of similarities in pairs and the method of triads is that subjects can make judgements about the entire set of objects in a relatively short time, even when a large number of objects is involved. In addition, a large number of pairs might have affected subjects’ motivation in a negative way. The instruction was as follows:

„You are about to see 32 pictures of roads outside the built-up area. Your task is to make a useful classification of these pictures. Try to imagine yourself driving on the road and ask yourself how you would behave or which behaviour you would expect from other drivers on the same road. Sort the pictures in such a way that the behaviour on the roads in a pile is the same, and different from the other piles. There is no good or wrong sorting; make piles that you find useful yourself. Do this quickly, without thinking too long. You are free in choosing the number of pictures within each pile and the total number of piles. If you have any questions you may ask the experimenter now.“
The 32 pictures were placed on a large table in a fixed order. This created a homogenous test situation in which the effect of order would be the same for all subjects. Correction was allowed, but not explicitly mentioned in the instructions. Subjects had to act as in reality, where the impression of a road triggers categorisation. After the subjects had completed the sorting to their satisfaction, the experimenter registered the labels of the pictures in the piles. The labelling of pictures was done so that no information about the official classification was given to the subjects.

For all three conditions a similarity matrix was made, in which the similarity between pictures \( x \) and \( y \) was defined as the number of subjects who placed \( x \) and \( y \) in the same pile. To give a clear presentation of the clusters of pictures (the obtained subjective categories), a hierarchical cluster analysis and a nonmetric multidimensional scaling (MDS) were performed on the similarity matrices (Guttman-Lingoes algorithm; Theeuwes & Diks, 1995b).

In hierarchical cluster analysis (Euclidean distances, complete linkage method) a tree structure develops (dendrogram), in which the clustering of the most similar road environments was followed by the clustering of the second most similar road environments and so forth. A dotted cut-off line (see Figure 2a) indicates the number of subjective categories that corresponds to the number of official categories (A, B, C, D). The subjective categories were labelled as category I, II, III and IV, because a subjective category could contain road environments of various official categories.

The results of the multidimensional scaling analysis reflect where the road environments are situated compared to each other in a two-dimensional space. More similar road environments are closer together in the two-dimensional space. The graphs give an indication of the construction of the arisen subjective categories. For all analysis of the categorisation task, Statistica 5.0 (StatSoft, 1995) was used.

### 2.2.2 Results

Before the data were transformed into dendrograms and graphs, the number of underlying dimensions had to be determined. To do this stress values were studied. Stress values give an indication of the amount of unexplained variance. It appeared that with three underlying dimensions including another dimension not much extra explained variance was added (Kaptein & Claessens, 1998). Therefore an analysis with three underlying dimensions was chosen. The according stress values for the three road design conditions were, respectively, 9.5%, 7.5%, and 11.5%. To give a clear presentation, only two of the underlying dimensions are represented in the graphs. Figure 1, 2, and 3 show the results of the Multi-Dimensional Scaling analysis to what extent pictures were seen as similar for CR, SER, and mixed road designs, respectively.

**Current road design versus Self-Explaining road design**

Road environments for both the CR and the SER design were divided into four categories. As expected, a systematic application of road characteristics for the Self-Explaining Roads led to a cognitive road classification that was more in accordance with the official road category system. Only a small variety of road environments within each self-explaining road category was present, because road characteristics
were homogeneous within one road category and were systematically varied across road categories.

For Current Roads, motorways were categorised in the same group (I) as two motorroads (B) and one 80 km/h road for fast traffic (C). It is likely that guard rails in the picture of motorroad B3 and the picture of 80 km/h road for fast traffic C7 misled the subjects (see Appendix I), because this element has been shown to subjectively belong to the road category ‘motorway’. For motorroad B2 it was not clear why it was categorised as a motorway. In the SER condition, motorways were seen as a uniform road category.

Another problem with Current Roads was that motorroads (B) and 80 km/h roads for fast traffic (C) were mostly seen as roads of the same category (II). The most important difference between these two road categories seemed to be the number of carriageways. 80-km/h roads for fast traffic that had a dual carriageway were all categorised as motorroads. All 80 km/h roads for fast traffic with the SER design had a single carriageway, whereas all motorroads had a dual carriageway, in order to take care of this problem. On the other hand, a motorroad that seemed to have a single carriageway was categorised as an 80-km/h road for fast traffic. Because of vegetation between the carriageways, road B1 looked like a single carriageway. Road users simply could not see the other carriageway. Another motorroad had a side-road within sight, which was probably the reason that it was categorised as an 80-km/h road for fast traffic. The rest of the motorroads from the SER design was seen as one uniform road category.

Finally, groups III and IV of Current Roads contained 80 km/h roads for all traffic with centre-line markings and 80-km/h roads for all traffic without centre-line markings, respectively. This indicated that 80-km/h roads for all traffic (D) were divided on the basis of the presence or absence of centre-line markings. 80-km/h roads for all traffic were seen as one uniform road category.

Self-Explaining versus Mixed road design

Mixed Roads were divided into six categories. Just as in the CR design there was a large variety of road environments within each road category. The subjective categories were almost the same as with the CR design. The only difference was that the two categories with 80 km/h roads for all traffic (D) in group III and IV were closer together in the graph, and that motorroad B4 was put into the category motorways.

Self-Explaining Roads from the SER design were categorised differently from the identical self-explaining roads from the Mixed design. Self-explaining roads from the mixed design were categorised as they were in the CR design when they were not manipulated. This indicates that for the whole set of road environments to which a road belongs, the context is important for how roads are categorised.
Figure 1: Subjective categories of the subjects assigned to the *Current Road design* with three underlying dimensions and a stress value of .095.

Figure 2. Subjective categories of the subjects assigned to the *Self-Explaining Road design* with three underlying dimensions and a stress value of .075.
Figure 3. Subjective categories of the subjects assigned to the *Mixed road design* with three underlying dimensions and a stress value of .115.
2.3 DRIVING SIMULATOR TASK

To investigate the effect of a Self-Explaining Road design on driving speed, a driving simulator task was used. The experiment was carried out in the driving simulator of the TNO Human Factors Research Institute. A description of this driving simulator is given elsewhere (e.g. Hoekstra, Van der Horst & Kaptein 1997). Differences between experimental conditions as found in driving simulator studies are very well comparable with results from reality (Riemersma, Hoekstra & Van der Horst, 1988; Tenkink & Van der Horst, 1991; Kaptein, Theeuwes & Van der Horst, 1996). Although caution is needed with interpretations about absolute speed levels, because commonly subjects may tend to drive faster in a driving simulator than in reality, relative driving speed seems to be valid (Van der Horst & Hoekstra, 1992).

The stimuli were computer-generated images projected on the screen in front of the driving simulator. This task environment was a data base for the ESIG 2000 image generation system (pictures from it were also used in Experiment 1), consisting of a set of objects (houses, trees, cars, guard rail etc.). Each object consisted of several surfaces and each surface had a number of characteristics that specified form, colour, texture and shading. The surfaces of each of these objects were arranged in a way that made the object look correct from each point of view. The objects among themselves were arranged in a way that the total database looked correct from any point of view. The network of roads fulfilled the following requirements: there was no other traffic, there were no traffic signs concerning the speed limit or the official category of the road and there were no sharp curves in the road. The road environment was a reconstruction of existing/official roads (see Table I). A distance of 1300 m was chosen so that after acceleration, when a constant driving speed was maintained, a long enough section was available. After 900 m a curve was encountered, slight enough to exclude any influence on driving speed (ROA, 1991; 1993). The curves were designed in four combinations: R = 1000, 30°; R = 1000, 40°; R = 2000, 30° and R = 2000, 40°. They were semi-randomly assigned to the different road environments. Each category consisted of two road environments per combination.

2.3.1 Procedure

Subjects drove through a route in the database. Before driving in the driving simulator began, subjects read the following instruction:

"You are taking part in a driving simulator study about driving behaviour on roads in different situations. You have to imagine yourself making a ride on a quiet weekend day at noon. Behave as you think is most appropriate in the given road environment, whereas you have to take the possible presence of other traffic into account. You will drive three times for a period of more than half an hour with resting periods of more than half an hour. During the test you will continuously stay in contact with the experimenter via an intercom in the car. Afterwards you will be asked to fill out a short questionnaire. If you have any questions you can ask them now."

For each road design a separate group of subjects made three rides through all roads in the database (between-subjects design: between conditions different subjects were tested). Each subject would drive for about two hours in total, divided
into three sessions of approximately 40 minutes. One session consisted of a sequence of 32 rides over a distance of 1.3 km each. The repetition was included in order to give subjects a chance to get used to a network of (new) roads, and to be able to build up their own subjective set of road categories. A choice of driving speed had to be made with the presence of other traffic in mind.

After a ride, each subject was asked to fill out a questionnaire that was the same in all road design conditions and reflected the reason for their driving behaviour on the roads they had been driving on. For the questionnaire results the reader is referred to Kaptein & Claessens (1998).

During each ride the average driving speed and the standard deviation of driving speed over the road section between 800 m and 1100 m (within this range driving speeds appeared to be most stable) were recorded. The average speed each subject drove for each road environment, per road category, per repetition (first, second and third ride) and the standard deviations of the average speed per subject, per road design (condition), per road category, per repetition were analysed.

A MANOVA was used to test significance of the univariate repeated measures factors that had more than two levels. It was investigated whether driving behaviour over three repetitions between the eight road environments for each of four road categories differed significantly between Current Roads and Self-Explaining Roads, and whether standard deviations and variances were relatively small within and large between road categories depending on design condition. A Tukey test was used to further investigate the possible cause of main-, or interaction effects. For all analyses of the driving simulator task, Statistica 5.0 (StatSoft, 1995) was used.

### 2.3.2 Results

**Current Roads versus Self-Explaining Roads**

MANOVAs were performed for official road categories on both average driving speed and standard deviations. Main factors for the official road categories were road design (CR, SER), category (A, B, C, D), repetition (3 levels) and road environment (8 levels) with average driving speed as a dependent variable. Road design was a between-subjects variable. Road environment was nested within road category. By road design condition, each set of road environments represented a road category. Table III shows means and standard deviations from driving speed of sixteen subjects by road design by road category A, B, C and D for official road categories.

<table>
<thead>
<tr>
<th>RC</th>
<th>CR design</th>
<th>SER design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Means</td>
<td>St.dev.</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R1 r2 r3</td>
<td>r1 r2 r3</td>
</tr>
<tr>
<td></td>
<td>117.5 117.3 120.2</td>
<td>5.8 5.0 4.3</td>
</tr>
<tr>
<td>B</td>
<td>101.0 103.0 104.4</td>
<td>12.6 10.6 12.0</td>
</tr>
<tr>
<td>C</td>
<td>94.0 96.1 96.8</td>
<td>8.5 8.5 9.0</td>
</tr>
<tr>
<td>D</td>
<td>82.8 83.7 86.1</td>
<td>9.5 8.0 7.2</td>
</tr>
</tbody>
</table>
Significant main effects on average speed of road category \([\text{Rao R} (3,26) = 59.12, p<0.001]\) and repetition \([\text{Rao R} (2,27) = 4.50; p<0.05]\) were found. On each next-higher official road category subjects drove faster and with each repetition subjects drove faster. There was no interaction found for road category and repetition. A significant interaction of road design and category was found \([\text{Rao R} (3,26) = 7.35, p<0.01]\). A post-hoc Tukey HSD test showed that average driving speed from road categories B and D of Current Roads differed significantly from road categories B and D of Self-Explaining Roads. For both categories subjects drove significantly faster with the SER design. No further significant effects were found.

Figure 4 shows standard deviations of average driving speed by official road category for Current Roads and Self-Explaining Roads. For both design conditions, road category A had a significantly lower standard deviation than the other road categories. In addition, road category B from the CR design had a significantly higher standard deviation than the other road categories from this design. A significant main effect for standard deviations of repetition was found \([\text{Rao R} (2, 28) = 3.75, p<0.05]\). Standard deviations from the average driving speed became smaller with each repetition. A significant interaction of road design and road category was found \([\text{Rao R} (3, 27) = 3.11, p<0.05]\). A Tukey HSD test showed that standard deviations in road category B of Current Roads differed significantly from that of Self-Explaining Roads. Standard deviations for road category B were significantly lower for Self-Explaining Roads than for Current Roads. No further significant effects were found.

**Mixed road design versus Self-explaining road design**

A separate MANOVA was performed on the effects on average driving speed for the two SER road environments that were \textit{identical} in both the Mixed and in the SER designs. The two identical road environments in both designs (SER environments SER versus SER environments Mixed) elicited the same average driving speed. This indicates that the whole set of road environments, the context, had not influenced subjects’ driving speed significantly for these roads. However, standard deviations of speed from road environments from category A (Motorways) in the SER design were significantly lower than those in the Mixed design. On Self-Explaining roads from the
Mixed design, standard deviations of the third repetition were significantly higher than those from the third repetition in the SER design. The whole set of road environments had influenced the homogeneity of subjects’ driving speed within road category A.

2.4 GENERAL DISCUSSION

The influence of a self-explaining road design on cognitive road classification, driving speed and homogeneity of driving speed within road categories can be divided into a direct effect of road characteristics and an indirect effect of the whole set of road environments.

Design changes for roads from the SER design, led to more appropriate subjective road categorisation. Road environments from the subjective categories of the SER design were more similar within one road category and more different between road categories. They were more in accordance with the official road categories than those from the CR design. For example, the category motorroads, that was worst categorised in the CR design, came to be identical to the official road category motorroads. In addition, when SER environments were part of a set of self-explaining roads they were categorised more in accordance with the official road categories than when they were part of a fuzzy set of road environments. Thus, a more selective and systematic application of road characteristics to types of roads led to cognitive road classification that was more in accordance with the official road category system, in which the context of road environments influenced cognitive road classification.

Design changes for roads from the SER design led to significantly higher driving speeds in the road categories Motorroads and 80 km/h roads for fast and slow traffic. Because of this increase, there was a trend in which motorroads were easier to distinguish from 80 km/h roads for fast traffic, but in which the distinction between 80 km/h roads for fast traffic and 80 km/h roads for fast and slow traffic became worse. SER design also led to a significantly more uniform (homogeneous) average driving speed in the road category motorroads compared to that from CR design. Thus, a more selective and systematic application of road characteristics to types of roads led in some cases to driving speed that was more in accordance with driving speed as meant for the official road category system.

Subjective road categories in the SER design, that were all more in accordance with the official road classification, elicited also a more balanced driving speed for this design. A higher driving speed was maintained on each higher order road category. It has not been proved that this correlation between cognitive road classification and driving speed is causal.

In category A SER environments (Motorways) within the set of Self-Explaining Roads (better classified in accordance with the official road classification), subjects maintained a significantly more uniform driving speed within road categories, than they did in road environments A that were part of a fuzzy set of roads (CR environments). This indicates that the context did have its influence on the within variance of driving speed from road categories. Thus, a better cognitive road classification, led in one case (road environments A, motorways) to driving speed
that was more in accordance with driving speed as meant for an official road category.

Repetitions in the driving simulator experiment were used to provide subjects a clear impression of the available set of road environments, so they could determine their driving speed on the basis of this set of environments (context). In both designs subjects drove faster and more uniformly within road categories of each repetition. The speed curves in each road category did not differ in the three repetitions. For all road categories one impression seemed to be enough to determine subjects’ relative driving speed, but more rides were needed to increase uniformity of driving speed for each road category. Thus, road characteristics are an important determinant of driving speed, but the whole set of road environments is an important determinant of the homogeneity of driving speed within road categories.

This study gives evidence for the effect of self-explaining road design on cognitive road classification, on driving speed and on homogeneity of driving speed within a road category. It also proves that cognitive road classification does not affect absolute or relative driving speed, but that it does affect the homogeneity of driving speed within road categories. It is possible that the salience of road characteristics in these road categories dominates the influence of the whole set of road environments. It is also to be expected that cognitive road classification influences other driving behaviours more strongly, such as anticipating driving styles and that the level of driving speed relies more on road characteristics.

REFERENCES:


APPENDIX I  Stimuli from the picture sorting task

CR Design
SER Design