Influence of basic environmental characteristics on driving speed

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Abstract

To date, inappropriately adjusted driving speed is still one of the main causes for traffic accidents (Aarts et al., 2011). Recent theoretical approaches of modeling speed behavior assume that choice of speed is partly determined by environmental characteristics (e.g. Fuller, 2005). In addition, empirical studies revealed an influence of basic changes of environmental characteristics (e.g. Godley et al., 1999; Manser & Hancock, 2007) on driving speed. However, these investigations exclusively discussed changes of environmental characteristics on the ground area (e.g. street surface) or on the lateral (e.g. tunnel walls) area of the peripheral visual field. A variation of basic environmental characteristics on the upper area of the peripheral visual field (i.e. above the street) has not yet been investigated. The present paper investigates this question. Visual stimuli were introduced to a simple simulation with varying rates (high/low) and positions (lateral, upper or complete periphery). It was hypothized that 1) the number of additional information and 2) the position of this visual information in the peripheral visual field (see also Gibson, 1979) influences driving speed. Empirical results showed that both, the rate and position of stimuli significantly influenced driving speed and subjective dimensions such as task difficulty and subjective arousal.

Introduction

To date road traffic accidents still pose one of the most serious societal problems (Vaa, 2003). In 2010, a total of 2,411,271 million traffic accidents had been registered in Germany. On average ten persons died each day due to traffic accidents in 2010 (Statistisches Bundesamt Deutschland, 2011). Inappropriately adjusted driving speed is postulated as a main cause for these accidents (Statistisches Bundesamt Deutschland, 2011). According to theorists (e.g. Ranney, 1994; Brandenburg & Drewitz, 2010), a conclusive theoretical framework is necessary to relate existing empirical findings to each other, as well as to formulate generally acceptable explanations, predictions and more effective countermeasures.

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Regarding empirical evidence a wide range of factors have been postulated to be responsible for the choice of speed. Mostly, they focus on environmental characteristics (e.g. self explaining roads, Theeuwes & Godthelp, 1995) or driver characteristics (e.g. personal variables like sensation seeking; Goldenbeld & vanSchagen, 2007). However, despite the good explanatory power of these factors in a single study, overview papers often report heterogenous effects of each factor across several investigations (e.g. Elliot et al., 2003; Edquist et al., 2009). For instance, various studies investigated the influence of transverse lines on the choice of speed. Whereas some experiments revealed speed reductive effects up to 11km/h due to the application of transverse lines (e.g. Goodley et al., 1999), others did not show any significant impact of transverse lines on driving speed after a certain amount of time, or reported highly variable results (e.g. Fildes & Jarvis, 1994). To account for this inconsistency of effects Brandenburg and Drewitz (2010) postulate two countermeasures. First, researchers should base their research agenda on models and theories, rather than on single effects only. Theories and models represent knowledge gained from a larger set of empirical results. Hence, inferences that are drawn from theoretically based experiments should be more stable than single effect experiments. Second, the reason for the instability of effects might lie in the interaction of different factors of the road environment (e.g. Brandenburg & Drewitz, 2010; Edquist et al., 2009; Aarts et al., 2011). Based on questionnaire data, Brandenburg and Thüring (2009) found that drivers almost always report multiple reasons for exceeding the speed limit. With respect to this issue Brandenburg and Drewitz (2010) emphasize the role of basic research methods to unravel interaction effects of different influencing factors. Hence, the present study utilises both a theoretical framework to elicit the research questions, and a basic research setting to focus on internal validity.

Theoretical background

Newer theoretical models of speed choice (e.g. Task Capability Interface Model (TCI), Fuller, 2005; Components of Speed Behavior Model (CSB), Brandeburg & Thüring, 2012) provide a richer explanatory basis compared to single-concept approaches like perceived risk (Wilde, 1982), motivation (Vaa, 2003), direct perception (Gibson, 1979) or intentions (Ajzen, 1991). These integrative models are able to integrate empirical results as well as existing concepts.

According to the TCI, drivers always attempt to maintain a certain level of task difficulty that derives from a constant comparison of the perceived task demands (TD) and drivers capabilities (C). According to Fuller (2005) task demands are defined as ”[...] plethora of interacting elements [...] such as visibility, road alignment, road marking, road signs and signals, road surfaces and curve radii, camber angles and so on.“ (Fuller, 2005, p. 464). In addition, perceived drivers' capabilities are determined by human factors like experience or training. In regard to Fuller (2005) “Driving task difficulty is inversely related to the difference between driver capability and driving task demand.” (Fuller, 2005, p. 470). The dynamic comparison of task demands and capabilities results into the choice of speed. If the prevailing task demands are higher than drivers' capabilites, drivers will decelerate. In contrast, drivers will accelerate if task demands are lower than drivers' capabilities (Fuller, 2005, p. 466). However, if task demands equal drivers' capabilities the driver starts loosing control over his vehicle. Hence, following the assumptions of Fullers (2005) TCI model, one can predict that additional elements in the road environment will increase task demands and subjective task difficulty. Hence, given that drivers' capability remains constant, driving speed should decrease. Empirical data from previous investigations support this conclusion. For example, in literature, many effects of alterations of roadside environment on speed choice are reported (e.g. Martens et al., 1997; Horberry et al., 2006; Aarts et al., 2011). For example Elliot et al. (2003) as well as Martens et al. (1997) report that trees at the roadside lead to slower speed compared to road sections without objects on their periphery. De Ridder and Bouwer (2002) elaborated this effect by showing that even the type of roadside vegetation manipulates drivers' speed choice differently. Their data shows, that larger vegetation (e.g. trees) lead to slower speeds than smaller vegetation, i.e. bushes. Going even further van der Horst and de Ridder (2007) showed in their driving simulator study, that trees only influence speed choice if they were placed within the distance of two meters to the road side.

The present investigation makes use of these results by showing stylized tree-like elements in the lateral visual field (road side close to the road) of the driver. Additionally, it was tested if the effects of the roadside environment hold for the upper peripheral field (i.e. visual field above the street) as well. Again, this question was not yet a subject of investigation. However, since elements in the area of drivers' vision are expected to affect his speed (see also Gibson, 1979), the whole peripheral visual field should be investigated regarding its usefulness as additional space to present supplementary information unobtrusively. Based on the Task Capability Interface model of Fuller (2005) and the empirical effects, two hypotheses can be derived for the present study:

Hypothesis 1 (rate of informational cues): The higher the number of additionally added informational cues in the driver's peripheral visual field, the less the driving speed and the higher subjective task difficulty and subjective arousal.

Hypothesis 2 (position of informational cues): The more areas present additional, informational cues in the drivers' peripheral visual field (top, sides, both), the less is the driving speed and the higher subjective task difficulty and subjective arousal.

Regarding the second hypothesis, one can argue that a presentation of additional information in more than one field always changes the total number of elements. Of course, the present study controls for that argument by presenting more complex stimuli rather than more of the same. Still, a block of driving situations was added to the study. This second block investigates whether additional cues in more than one area of the visual field or the plain number of elements results into different driving behavior. Therefore this second block shows the same number of elements as in the first block, but in randomized order. Hence, if these randomized elements lead to similar effects than the more complex stimuli in the first block, both effects are due to a different number of elements in the peripheral visual field. In contrast, if the results between both blocks differ, position of informal cues matters.

Method

Participants

A total of N = 40 subjects participated in the experiment, 25 (62.50%) were male and 15 (37.50%) female. Their age ranged from 21 to 58 years (M = 27.80, SD = 7.39) and mean annual mileage was about M = 4917 km (SD = 5681). Participants obtained a valid driving license for about M = 9.40 (SD = 7.03) years. On average they operated a vehicle on about two days a week (M = 2.05, SD = 1.79). Mean accident rate for the last five years was low (M = 0.50, SD = 0.93). Subjects received 10 Euros for their participation.

Material

In the present study we used a simple driving simulation and a questionnaire for subjective measures. The driving simulation consisted of a large rear projection screen (2.00m x 1.50m) showing a straight rural road in a plain, green environment and excellent visibility conditions. The only speed indicator was the movement of the centre strip, separating both driving directions (see fig. 1). Subjects were able to operate the simulation by pressing the „up“ arrow on a keyboard to accelerate and the „down“ arrow to decelerate. Speed could be maintained by pressing the acceleration key in equally short time intervals. In case of no key presses, speed decreased. The questionnaire for the assessment of subjective experience asked subjects if they experienced (1) the task as being difficult and (2) subjective arousal. Both questions were administered with a seven point likert-type scale ranging from 1 = not at all, 2 = very few, 3 = few, 4 = normal, 5 = fairly, 6 = strong to 7 = very strong. Finally, participants were asked which speed they went at the end of each trial.

Procedure

First, subjects were informed about the scope of the study and the rules for data privacy. Then they were closely placed (ca. 30 cm) in front of the rear projection screen, holding a keyboard in front of them. Participants were instructed to focus on the vanishing point of the road, which was set to eye height for each subject. To get used to the artificial situation, subjects drove one test trial that resembled the baseline. This condition differed from the treatments (shown in figure 1 and 2) only by the absence of the black bars in the drivers' peripheral visual field. Subjects' task was to set the speed to the appropriate value at each point in time during the simulation. Throughout the experiment participants always completed the baseline first that was attached to each of the 11 experimental trials. Hence a trial consisted of a baseline and a subsequent experimental condition. Each baseline took 45 sec. at maximum speed (approx. 250 km/h). Each experimental condition was set to 90 sec. at maximum speed. After each trial participants answered the questionnaire assessing the subjective experience for the last experimental condition. The whole experiment took about half an hour.

Experimental Design

Two separate experimental blocks were conceptualized. The first one comprised two within-subject variables: (1) number of planes within the peripheral visual field that held additional information and (2) number of elements in each plane. The number of planes showed three steps: complete peripheral visual field, lateral visual field and upper visual field. The second factor, number of elements in each visual field, was realized in two steps: high and low number of elements (figure 1). All of these elements were shown in a constant systematic arrangement. The second block – adopted as an experimental control block - comprised only one within-subjects variable: the number of elements (low to high) but with a constantly random arrangement (figure 2). Therefore the total number of elements presented in the six cells of the first block was also adopted within the five cells of the second block. Both experimental blocks were counterbalanced over subjects and all experimental conditions within one block were randomly assigned to the participants. Objective and subjective driving speed, as well as subjective task difficulty and arousal, were assessed as dependent variables for each trial.

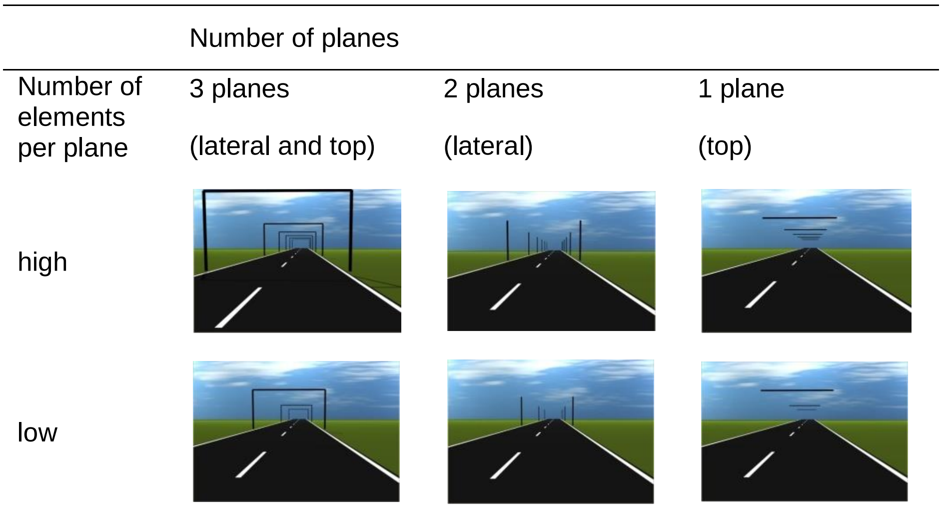

Figure 1. Visualization of the experimental conditions of the first block

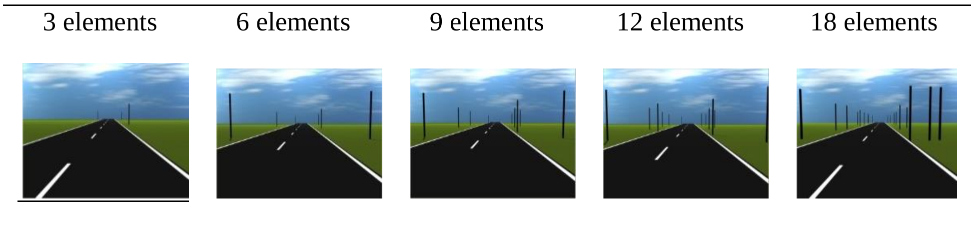

Figure 2. Visualization of the experimental conditions of the second block

Results

For the analysis of block one a MANOVA containing the two factors number of planes in the peripheral visual field (complete, lateral, top) and number of elements per plane (high, low) over all dependent variables was computed. With respect to the objective measures, we analyzed the first 60 seconds after subjects entered the experimental conditions. Tables 1 and 2 summarize the results. Additionally, the effect size η^2 after Cohen (1988) and Bonferroni corrected post-hoc comparisons are reported if applicable. To test if block one and two result into similar results, a second MANOVA with number of elements as within-subjects factor with 5 steps (see Table 2) and subjective and objective speed as well as arousal and task difficulty as dependent variables was computed.

In general, the analysis of block one revealed significant main effects of the both factors for objective speed and arousal (see Table 1 for detailed results). Therefore subjects drove significantly slower if more elements were shown in the drivers' peripheral field of view compared to fewer elements.

Table 1. Main and interaction effects for each dependent variable of the first block

Dependent variable	**Effect**	**F (df1,df2)**	**p**	**η^2**
number of elements per plane (N)	**objective speed**	**(1,39) = 5.69**	**0.02**	**0.13**
	subjective speed	(1,39) = 0.10	0.75	<0.01
	arousal	**(1,39) = 3.33**	**0.08**	**0.08**
	task difficulty	(1,39) = 0.82	0.27	0.03
number of planes (P)	**objective speed**	**(2,78) = 5.15**	**<0.01**	**0.12**
	subjective speed	(2,78) = 1.27	0.29	0.03
	arousal	**(2,78) = 10.27**	**<0.01**	**0.21**
	task difficulty	**(2,78) = 11.67**	**<0.01**	**0.23**
N x P	objective speed	(2,78) = 1.60	0.21	0.04
	subjective speed	(2,78) = 0.25	0.78	<0.01
	arousal	**(2,78) = 3.03**	**0.09**	**0.07**
	task difficulty	(2,78) = 0.55	0.58	0.01

Note: Significant effects and tendencies are printed in bold. Size of effects: small: $0.01 < \eta^2 < 0.08$, medium: $0.08 < \eta^2 < 0.14$, large : $0.14 < \eta^2$.

Additionally, subjects reported higher levels of arousal in conditions with more elements in the peripheral visual field, compared to fewer elements. Regarding the position of cues, participants were slower, more aroused and reported higher levels of task difficulty if all three planes were filled with additional elements compared to two or one plane only (p's < 0.05). However, it did not affect behavior nor subjective experience if two planes or one plane was used to present additional information (p's > 0.05). With respect to the analysis of the second block, results were similar to the evidence in block one. The number of elements affected objective speed as well as subjective data. Paralleling the results of block one, post-hoc tests revealed that the largest manipulation affected drivers' behavior only. Hence, subjects drove significantly faster and reported less arousal and less task difficulty if three elements were presented compared to 18 elements (Table 2).

Table 2. Main effect data for each dependent variable of the second block

Dependent variable	F (df1,df2)	p	η^2
objective speed	**(4,39) = 2.03**	**0.09**	**0.05**
subjective speed	(4,39) = 0.93	0.45	0.02
arousal	**(4,39) = 2.89**	**0.02**	**0.07**
task difficulty	**(4,39) = 6.80**	**<0.01**	**0.15**

Note: Significant effects and tendencies are printed in bold. Size of effects: small: $0.01 < \eta^2 < 0.08$, medium: $0.08 < \eta^2 < 0.14$, large : $0.14 < \eta^2$.

Discussion

The goal of the present study was to examine whether environmental factors influence speed choice and subjective its representation. Therefore a basic experimental style driving simulator study was conducted in a laboratory setting.

With respect to the environmental characteristics in block one, both factors showed to have an impact on objective and subjective variables. For example, a higher number of elements per plane lead to a decrease in speed and an increase in arousal compared to a lower number of elements per plane. No changes were observed for task difficulty and subjective speed. Regarding objective speed, the effects of the number of elements are in line with previous research (e.g. Martens et al., 1997; Elliot et al., 2003; Edquist et al., 2009). For example Martens et al. (1997) showed that elements at the roadside did alter speed behavior compared to no elements in the road environment. With respect to the missing effect of subjective task difficulty, one possible reason for the missing change in this variable might lie in its conceptualization. According to the CSB (Brandenburg & Thüring, 2012) and the TCI (Fuller, 2005), task difficulty is defined as the subjectively experienced difficulty to accomplish a driving goal (i.e. to keep a certain speed). In the current experiment, subjects were expected to feel a higher difficulty to keep their (baseline) speed when entering an experimental condition presenting a high number of elements. Assuming that drivers' abilities remain the same, such conditions should have increased the amount of information to be processed by the subjects. Hence participants should have decelerated. Possibly the change from a small number of elements per plane to a high number was not large enough to let subjects experience a strong feeling of task difficulty. Of course, elements were clearly visible for the drivers but they were black and relatively small in comparison to the rest of the environment.

A second explanation aligns to similar results of Lee et al. (2003) and Horberry et al. (2006). Their studies were designed to assess both within-vehicle distraction and the possible distraction due to environmental characteristics (e.g. a higher/lower complexity) in the roadway environment. Although rather complex environments, as opposed to simple environments, led to slower mean speeds the subjectively rated workload did not significantly differ between conditions. One possible explanation is that driving is such a highly automated task that drivers are not aware of the cognitive demands regarding the complexity of an environment (Lee et al., 2003). Hence, subjects do not expend more effort and, although the driving performance is severely impaired, the workload remains unaffected (Wickens & Liu, 1988). However, task difficulty cannot be equated with cognitive load. Nevertheless, both ensure due to the subjectively perceived changes of the task demands (see also Fuller, 2005).

Aligning to the effects of number of elements per plane a higher number of textured planes in the peripheral visual field lead to a decrease in objective speed and an increase in task difficulty and arousal. In other words, a tunnel like impression (all three planes of the peripheral visual field are covered) of the roadside environment helps to decrease speed significantly. Therefore, results for the factor number of planes correspond to current models of speed choice (Brandenburg & Thüring, 2012; Fuller, 2005) and other empirical findings reported in literature (e.g. Serrano & Blennemann, 1992; Amundsen, 1994). Both studies investigated the impact of tunnels on speed choice. Especially Serrano and Blennemann (1992) showed that participants drove slower and reported unpleasant feelings (e.g. oppression) when entering and driving through a tunnel segment. Manser and Hancock (2007) also found strong decreases of speed in tunnel situations. Therefore present work indicates that safety effects of tunnels might be carried over into other situations. In daily life, for example, alleys where trees converge over the street might lead to tunnel like effects in terms of speed reduction.

Finally, results of the second block suggest that the amount of additional information influences drivers' perception of the driving situation and alters their behavior. In both blocks driving conditions with many elements differed from situations with fewer elements in their effects on choice of speed and drivers' experience of the situation. Hence, number of elements seems to be more important than its arrangement.

With respect to the practical implications of the study results, at least one conclusion for creating unobtrusive countermeasures against speeding comes up. Planting trees on the side of the road, like in the lateral conditions, as countermeasure against speeding needs to be evaluated. Our findings suggest, that setting up perceptual countermeasures does not work by itself as proposed by Gibson (1979). It rather seems that there has to be a sufficient level of perceptual stimulation for road users to regulate speed.

To sum up, the present work delivered supports current models of speed behavior (e.g. TCI, Fuller, 2005; Brandenburg & Thüring, 2012). A higher number of elements in the peripheral visual field as well as more planes with elements lead to lower speeds as well as higher arousal and task difficulty. However, the present study also shows, that subjective speed is not the same as objective speed. Upcoming studies should address this issue. In line with previous research (e.g. Denton, 1966) drivers seem to have a misrepresentation of their own speed. This is important for data assessment (see also Brandenburg & Drewitz, 2010) as well as contermeasures against speeding.

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