CHANGES IN OPTIC FLOW AND SCENE CONTRAST AFFECT THE DRIVING SPEED

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Abstract

While walking in a virtual environment, the optic flow can be manipulated to elicit the impression of moving faster or slower compared to the actual walking speed. In this study, we investigated whether participants in a driving simulation are similarly sensitive to changes in the velocity of the optic flow. Moreover, it has been shown that drivers' speed perception is affected by the contrast of the scene. For instance, a spatially uniform contrast reduction, simulating, fog, leads to a lower perceived speed and, therefore, to a higher produced speed (Snowden, Stimpson and Ruddle, 1998). In our driving simulation study, we tested speed perception and production under more realistic fog conditions and manipulated the motion of the road surface to alter the optic flow. Results showed that with an increased optic flow velocity drivers slow down, with a slower optic flow they speed up. These behavioural effects are more pronounced compared to the effects during walking, emphasizing once more the importance of optic flow for speed estimation in driving simulations. Furthermore, in our scenario, the simulated fog led to lower produced speed, and not to speeding. This result supports the interpretation that fog leaves visible only peripheral portions of the scene, where high angular velocities signal a higher driving speed.

Résumé

Introduction

The perceived speed during driving depends on many environmental factors. In real driving situations, it has been shown that the perceived speed is affected by auditory information (Denton, 1966), luminance (Triggs and Berenyi, 1982), driving experience (Recarte and Nunes, 1996) and traffic conditions (Conchillo, Recarte, Nunes and Ruiz, 2006). A number of studies employed driving simulations to determine the influence of different environmental and display factors on perceived speed during driving. The presence of objects in the periphery (Levine and Mourant, 1996) as well as an increased field-of-view (Osaka, 1988) leads to higher estimated speed, whereas Distler and Buelthoff (1996) have shown in a series of psychophysical experiments in a virtual environment that perceived ego-speed is influenced by the contrast and the spatial frequency content of the scene. Here we present a behavioural study on the role of contrast and optic flow on perceived speed using a driving simulation.

In driving simulations, the perception of the speed of self-motion relies mostly on visual information (Bartmann, Spijkers and Hess, 1991): even with motion cueing, vestibular and proprioceptive feedback can be either limited due to technological constraints (limited range of physical motion) or not informative (straight drive at constant speed). An important source of information for speed perception is the optic flow in the virtual driving environment. The optic flow (Gibson, 1950) is defined as the perceived visual motion of objects as the observer moves relative to them, and its role has been demonstrated for the perception and control of speed during walking (Baumberger, Flückinger, and Martin, 2000) and flying (Larish and Flach, 1990). During walking, changes in the velocity of the visual ground, thus altering the optic flow, lead to unintentional modulation of walking speed (Prokop, Schubert and Berger, 1997): a backward flow leads to a decrease in walking speed, whereas a forward flow leads to an increase in walking speed. The first question of the present study was whether altered optic flow in a driving situation affects speed choice in a manner similar to the walking situation. For this we manipulated the motion of the road surface along the driving direction.

A reduction of the contrast of two-dimensional luminance patterns produces a misperception of speed (Thompson, 1982; Blakemore and Snowden, 1999). Some authors argued that this effect is present also in conditions similar to those encountered when driving in fog (Distler and Buelthoff, 1996; Anstis, 2003). In a highly-cited experiment (Snowden, Stimpson and Ruddle, 1998) participants were asked to drive at a given target speed in a driving simulation, and as the scene became foggier, subjects produced faster speeds. This speeding behaviour has been interpreted as a reaction to a perceived lower driving speed caused by the scene contrast reduction due to the presence of fog. In that study, fog was implemented by blending a partially transparent surface over the rendered scene. With this method, however, an unrealistic uniform contrast reduction is applied to the scene, which does not simulate the real environmental conditions in fog. A more realistic account of fog conditions is a contrast reduction that depends on the distance of the objects to the observer. Recently, it has been found that an environment with exponential fog (i.e. contrast is exponentially reduced with distance), displaying a contrast gradient in depth instead of a uniform contrast reduction, leads to higher perceived speeds (Dyre, Schaudt, and Lew, 2005). According to the authors of this psychophysical study, a contrast gradient in depth leaves visible only the proximal portion of the visual scene, which contains the higher motion signals, thus increasing the global optic flow rate and consequently the perceived speed. The second purpose of our experiment was to investigate the effect of a realistic (exponential) fog on speed perception during an active task. As such we used the same experimental approach as Snowden et al. (1998), but were expecting opposite results given the psychophysical study above.

Method

Participants

Nine subjects (4 female and 5 male) with normal or corrected-to-normal vision participated in the study. All participants had a valid driving license for at least five years and were considered as experienced drivers since they declared an everyday car usage. They were paid and were naïve as to the purpose of the experiment.

Apparatus

The virtual environment was rear-projected at 60 Hz onto a flat 2.2 x 2 m screen with a resolution of 1280 x 1024 pixels (D-ILA projector, JVC DLA-C15) in an otherwise dark room. The projected scene covered a field-of-view of 75º x 70º from the viewing distance of 1.4 m. The Virtools software solutions and the VR Pack add-on allowed us to control the experiment and to distribute the scene rendering on a two-PC cluster. Participants operated the pedals and the steering wheel (Microsoft Sidewinder Forcefeedback Wheel) that was mounted on a desk (see figure 1). Pedal and steering wheel actions were received by a "master" computer (Windows XP), which updated position and orientation of the virtual car on basis of these inputs at a fixed frame-rate of 60 Hz. The updated values were sent to a "slave" computer to render and display the visual scene. The Havok Game Dynamics SDK, embedded in the Virtools Physics Pack add-on, was used to setup and fine-tune the behaviour of the virtual car and the sensitivity to the driving devices.

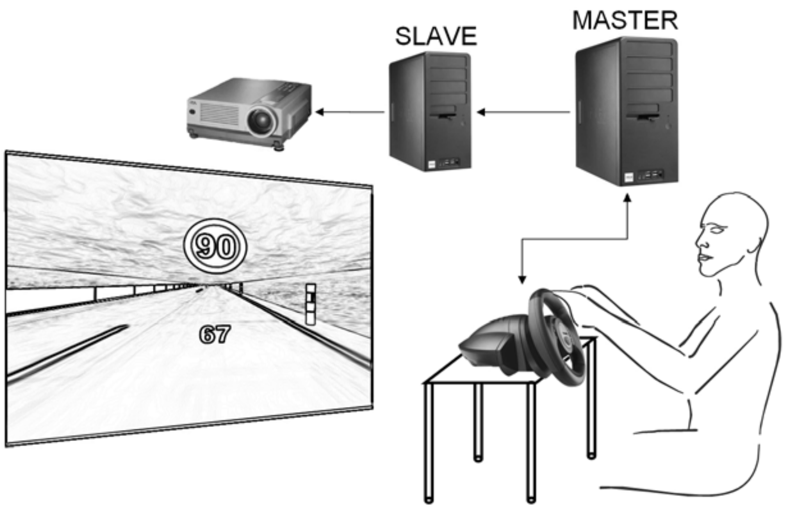
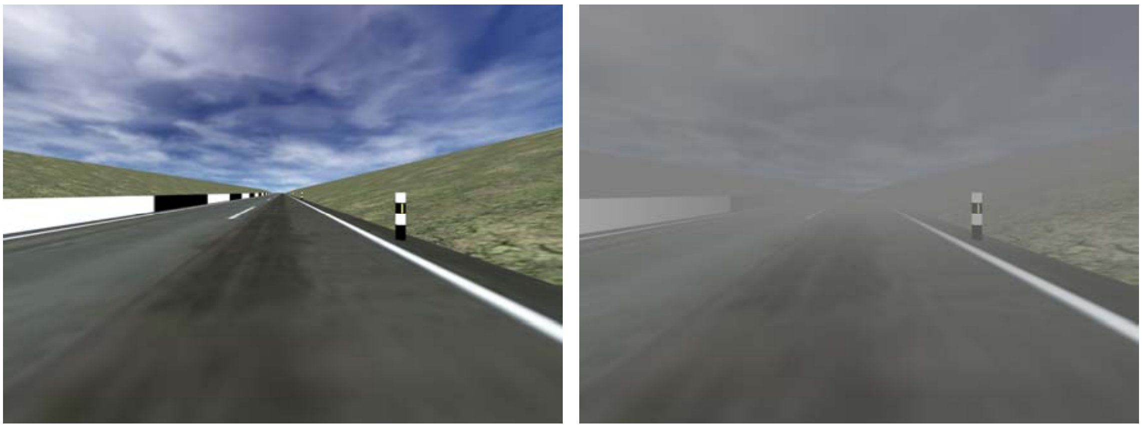


Figure 1: An overview of the experimental setup. A master computer records the signals from the input devices (pedals not shown) and updates the spatial coordinates of the driver's point of view; a slave computer renders the scene.

Environment

The virtual environment consisted of a modelled section (8 km) of a real local motorway, maintaining its geometry and course. Gentle curves and some height variations forced the driver to keep an active steering and speed control. The road had two lanes for each driving direction, separated by a traffic divider painted with large black-and-white stripes. Along the right side of the track road poles were set every 50 m. On both sides of the roadway a slanted plane covered with a grass texture simulated hill sides (figure 2a).



(a) (b)

Figure 2: The environment as it appeared to the observers: (a) the "clear" condition with a contrast of 0.7 (RMS_C; see text for details) and (b) the "foggy" condition with a contrast reduced to 0.3.

Experimental manipulations

The experimental manipulations included 3 target speeds (40, 60, and 90 km/h), 2 visibility conditions ("clear" vs. "foggy" environment with reduced contrast), and 3 relative road speeds ("faster", "same", and "slower"). The target speed was presented as a speed limit sign that appeared for five seconds at the beginning of each trial (see figure 1).

Fog and contrast

To obtain a realistic contrast reduction we created a real-looking fog in the environment according to an exponential model (exponent λ=-0.17): the fog became denser as the distance to the observer increased (figure 2b). At a distance of 27 m from the observer the visibility dropped down to zero. As suggested by Moulden, Kingdom and Gatley (1990), we quantified contrast of the scene as the normalized root mean square (RMS_C) of the luminance values of the displayed environment (i.e. ratio of standard deviation to mean of luminance values). The RGB pixel values of the scene were converted into their corresponding grey level values and their luminance distribution was determined based on the empirically determined function between luminance and grey values. Five snapshots were taken at random positions along the road to determine the average contrast. The RMS_C for the clear and the foggy condition was 0.7 and 0.3, respectively. The luminance of the scene ranged between 3 and 33 cd/m^2.

Relative road speed

The relative road speed factor consisted of a manipulation of the optic flow of the road's surface, implemented by scrolling the road's texture relative to the current driving speed (figure 3). In the "faster" condition, the optic flow of the road's surface appeared faster compared to the actual driving speed, since the texture of the surface was moved opposite to the driving direction. The speed of texture motion was always equal to 50% of the current driving speed. Similarly, in the "slower" condition, the texture was moved in the direction of driving (33% of the current driving speed) and the resulting optic flow from the road surface indicated a slower driving speed. The apparent speed in these two conditions amounted to 150% or 67% of the actual driving speed with regard to the motion of the rest of the environment. In the control condition ("same"), the optic flow corresponded to the actual driving speed. The manipulation factor was set to 1.5 after a pilot experiment had shown that no observer noticed a visual conflict with this amount of road texture scrolling.

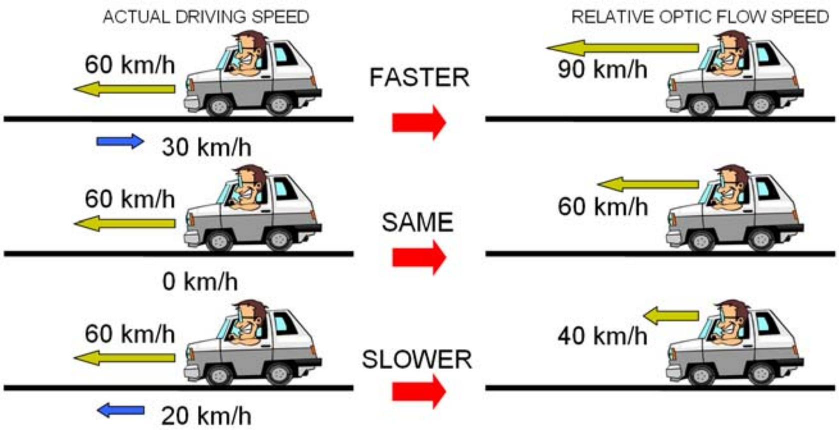


Figure 3: The "relative road speed" factor. Left: the arrows in front of the car indicate the actual driving speed, while the arrows beneath the road (black horizontal line) indicate the speed and the direction of the road texture scrolling. Right: the arrows indicate the expected perceived speed, if the speed judgments rely only on the optic flow of the road's surface.

The traffic divider, the road poles and the hill sides were not manipulated, in order to provide consistent cues with the actual driving speed.

Design and procedure

In the training phase participants learned to reproduce the target speeds required during the main experiment. No environmental manipulations were implemented, but a recurring digital tachometer, appearing at the center of the screen, provided the instantaneous driving speed for four seconds every ten seconds. With the tachometer being visible, the observer could compare and adjust their driving speed, whereas, when the tachometer was hidden, he/she was forced to look at the environmental optic flow and learn the relationship with the current driving speed. The three target speeds were presented five times, for an overall number of fifteen trials, each of which lasted one minute.

During the main experiment, the drivers' behaviour was tested under 18 randomly interleaved conditions (3 target speeds x 2 visibility conditions x 3 relative road speeds) in a withinsubject design. At the beginning of each trial, a speed limit sign appeared for five seconds in the middle of the scene indicating the required target speed. Participants were instructed to accelerate up to the indicated target speed, to keep it for five seconds and to terminate the trial by a button press. Feedback about the instantaneous speed was not provided anymore. The average speed during the last five seconds of each trial was considered as the produced speed for the statistical analysis.

Results

We conducted a repeated-measures analysis of variance (ANOVA) and found a significant main effect of each of the independent variables. The significant effect of the target speed ($F_{(2,16)}$=84.79, p<.001) indicates that people correctly executed the task and were able to discriminate between the three different driving speeds (the average produced speed was 54.6 km/h, 81.0 km/h, 110.1 km/h in the 40, 60 and 90 km/h conditions, respectively). Figure 4 illustrates the general overproduction of the driving speed of 18.6 km/h (31.3%). The overestimation effect was significant ($t_{(8)}$=3.99, p<0.01) and proportional to the target speeds. In fact, the normalised values of the produced speed did not differ over the three target speeds ($F_{(2,24)}$<1, p=0.52). This result is consistent with the known phenomenon of speed underestimation in driving (Recarte and Nunes, 1996). Actually, the general speed overproduction can be interpreted as driver's compensation to the underestimation of speed.

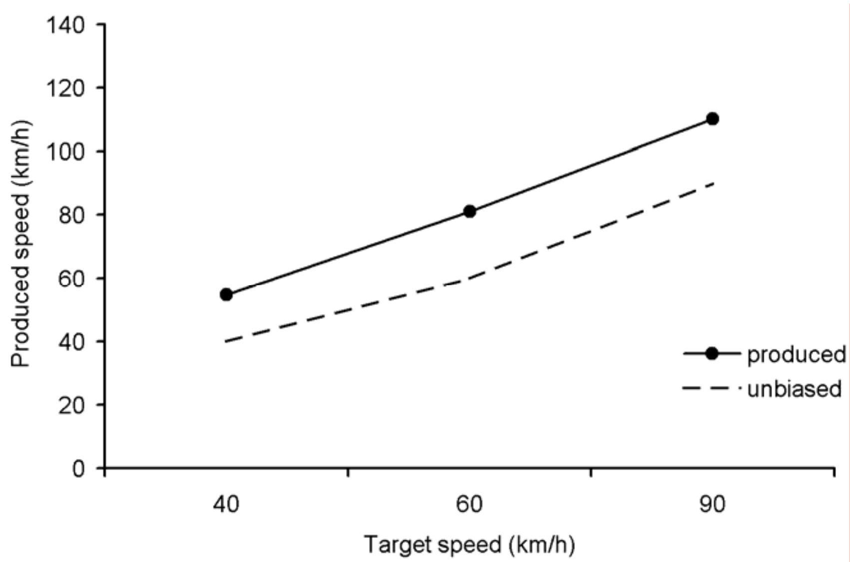


Figure 4: Main effect of the "target speed" factor and general speed overproduction. Dashed line indicates the correct speed.

We found a significant main effect of the relative road speed factor ($F_{(2,16)}$=80.11, p<.001). Participants increased the driving speed on average by 25 km/h (35%) when the texture motion indicated a slower speed and decreased by 7 km/h (-10%) when the driving speed appeared faster (figure 5). Interestingly, the amount of speed compensation appeared to be constant over the tested target speeds and not proportional to the driving speed.

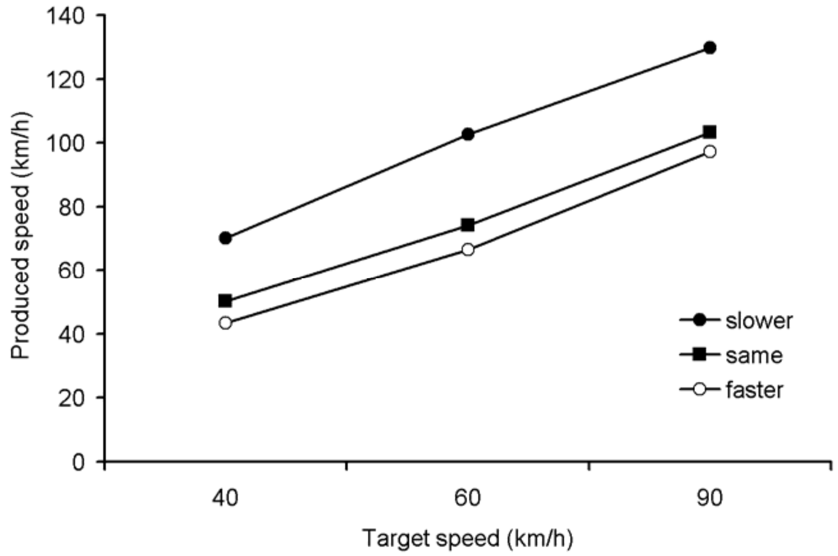


Figure 5: Effects of the “relative road speed” factor. With a road surface moving slower than the rest of the environment, drivers increased their driving speed, and vice versa.

We observed also a significant main effect of the visibility factor ($F_{(1,8)}$=38.05, p<.001), i.e. the produced speed in the “foggy“ conditions was lower (-8%) compared to the “clear“ conditions (figure 6). There was also a significant interaction between the target speed and the visibility factor ($F_{(2,16)}$=6.1, p<.05). A post-hoc comparison using Newman-Keuls test showed that at the lowest target speed of 40 km/h the difference between the clear and the foggy environment was not significant. No other high-order interactions proved to be significant.

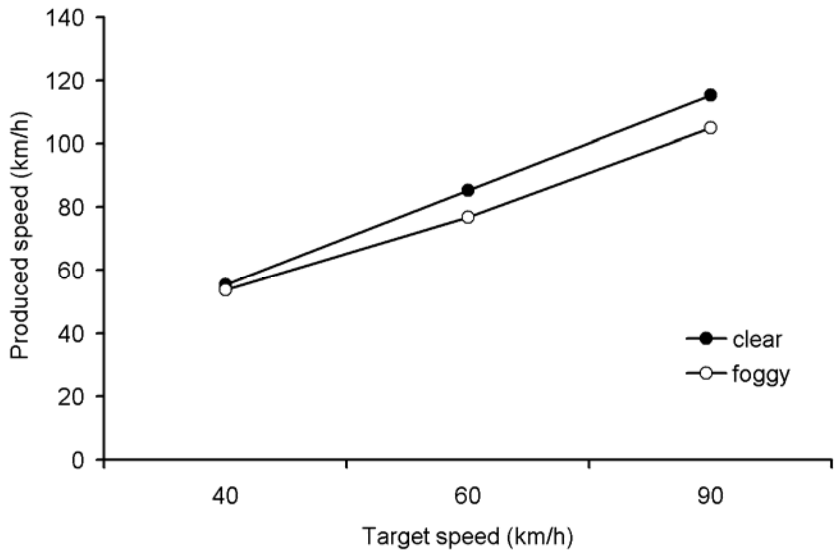


Figure 6: Effects of the “visibility” factor. Drivers slowed down in a foggy environment unless they were driving at the slowest required speed of 40 km/h.

Conclusions

In this study we have shown that the optic flow coming from the road ahead strongly affects the produced speed, despite the presence of other motion cues in the environment that provide a consistent information about the actual driving speed. This demonstrates the importance of that portion of the scene for the estimation of the actual driving speed. Our results go in the same directions as previous findings during walking: with an increased optic flow rate we slow down, with slower optic flow we speed up. The present effects are even more pronounced compared to the effects during walking. The interpretation of this might be that during walking a direct matching between physical effort and speed exist, but no equivalent source of information during driving. This emphasizes once more the role of visual motion and optic flow for speed estimation in driving simulations. Moreover, the present findings suggest that higher speed estimations will be obtained by scrolling the texture of the ground opposite to the driving direction, without any change in the geometry or the contrast of the scene. This effect could be exploited in driving simulators in which a general speed underestimation is reported.

A further result of the experiment is that in our realistic driving scenario the presence of fog led to lower speeds, and not to speeding. This result is in accordance with and extends previous psychophysical finding (Dyre et al., 2005), and supports the interpretation that fog masks distal portions of the scene, leaving only the proximal parts with higher angular velocities visible. As a result, the global rate of optic flow will indicate a higher speed (Watamaniuk and Duchon, 1992) and a driver intending to reach a particular target speed will level off at a lower speed.

In ongoing work we are comparing the behavioural results obtained in the present study with psychophysical estimates of perceived speed in the same clear and foggy environmental conditions. As a third condition we have tested the effect of a uniform contrast reduction, resembling the visual condition of Snowden et al. (1998). The first results seem to confirm that in foggy conditions the speed is indeed perceived as being faster than the actual speed. Interestingly, this fog effect was observed only for speeds of 60 and 90 km/h, but not at the lowest target speed of 40 km/h. This result is then in good agreement with the finding that drivers slowed down only at the higher speeds. Furthermore, this psychophysical result rules out more cognitive explanation of the speed reduction in fog (e.g. reaction due to safety considerations). Finally, we have observed that with uniform contrast reduction speed is indeed underestimated, consistent with previous results (Snowden, 1998). We conclude that driving in fog provokes people to adjust their speed, but to lower, not higher, velocities - an effect which has a rather perceptual origin.

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