THE INFLUENCE OF FOG ON MOTION DISCRIMINATION THRESHOLDS IN CAR FOLLOWING

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Summary: A possible explanation for close following in fog is that it would allow drivers to control headway more precisely by reducing motion perception thresholds. The purpose of our experiments was to determine the motion discrimination thresholds for closing and receding under normal and foggy conditions. An experiment and a pilot study were conducted on a driving simulator in which subjects were presented with a car following situation. Subjects had to press a button as soon as they detected that the lead vehicle was closing or receding, and their choice response time was recorded. Several visibility conditions were tested corresponding to different contrasts between the lead vehicle outline and the background, ranging from clear weather conditions to foggy conditions in which the vehicle could only be seen by its rear lights. Initial headway and lead vehicle acceleration were also varied. As expected, response times were longest with small accelerations and long headways. There was also an effect of visibility conditions with longer response times when the contrast between the vehicle outline and the background was 5% or less. Moreover, the reduction of response time corresponding to a reduction of headway was greater in fog than in clear conditions, at least in the given range of distances. This suggests that driving closer in fog may have a perceptual-control benefit in terms of a reduction in response times that partially offsets the reduction in time-headway. Driving closer may also benefit lateral trajectory control because the lead vehicle is less likely to be lost in fog.

INTRODUCTION

Traffic studies generally show that temporal headway (THW) is reduced in foggy conditions (Bulté, 1985; White, & Jeffery, 1980). One possible explanation for this reduction is that distances would be overestimated in fog, as was found by Cavallo, Colomb, & Doré (2001) in dense night-time fog. Another explanation for close following is that the lead vehicle could make lateral trajectory control easier, and hence would have to be kept in sight. The explanation we are interested in is that close following would allow a more accurate headway control (White, & Jeffery, 1980). Accurate headway control requires early detections of the lead vehicle accelerations and decelerations. It also requires differentiating closing and receding in order to have an appropriate reaction. The purpose of our experiments, then, was to determine the motion discrimination thresholds for closing and receding, in terms of choice response time, under normal and foggy conditions. We hypothesized that thresholds increase with fog, particularly for long headways.

FIRST EXPERIMENT

Method

Twelve subjects aged between 24 and 36 years took part in the experiment. All had driver's licenses and normal or corrected-to-normal vision. The experiment took place in a fixed-base driving simulator with three screens covering 150 x 45° of angular size. The total image resolution was 3840 x 960 and the refreshment rate was 30 Hz. Subjects sat in the driver's seat and were presented with a visual scene showing a car following situation. The lead vehicle was black and was followed at 50 km/h. The initial distance headway was either 16 m or 32 m. After a few seconds (3 to 8 s), the lead car started to decelerate or accelerate at 0.7, 3 or 7 m/s². Since the main effect of fog is a reduction of object contrast with distance, four visibility conditions corresponding to different contrasts were tested. Contrast is here defined as the difference in luminance between object and background divided by the luminance of the background. There were a clear weather condition (contrast of 100% between the vehicle and the background), two fog conditions with 22.3% and 5% contrasts between the vehicle and the background, respectively, and finally a fog condition in which the vehicle could only be seen by its fog lights since its outline could not be seen with a 0.25% contrast. The meteorological visual range (i.e., when objects are no longer visible) corresponding to those three fog conditions was 32, 16, and 8 m, respectively, when the distance headway was 16 m, and was 64, 32, and 16 m, respectively when the distance headway was 32 m. The subjects' task was to press one of two buttons as soon as they detected the lead vehicle was closing or receding. The response time was recorded.

Results

An analysis of variance was conducted on response time with four visibility conditions, two headway distances, three accelerations, and two motion directions. As previously observed (Boer, 1999; Duckstein, Unwin, Boyd, 1970), response time was longer with small accelerations and long headways. There was a main effect of visibility conditions ($p<.0001$) with longer response times (Newman-Keuls tests) when the contrast between the vehicle outline and the background was 5%, and when the vehicle outline was not visible as compared to clear conditions (Figure 1). For those two conditions, the response times increased respectively by 8.3% (0.1 s) and 23.1% (0.27 s) compared to the clear weather conditions. There was also an interaction between visibility conditions and distance headway ($p<.001$). Response time increased with fog for the 5% and 0.25% contrast conditions when distance headway was 32 m, whereas with the 16-m distance headway, response time increased with fog only for the 0.25% contrast condition (corresponding to an 8-m meteorological visual range).

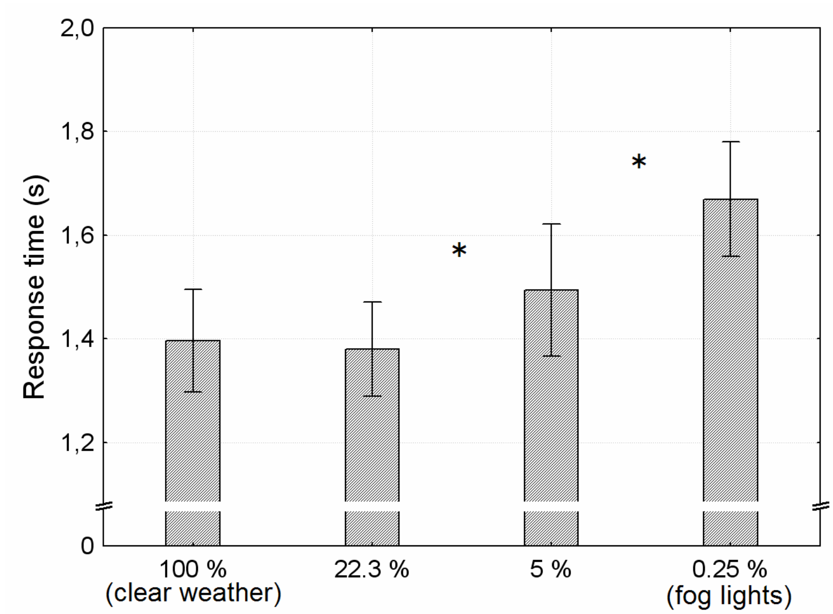

Figure 1. Response time as a function of contrast between vehicle outline and background

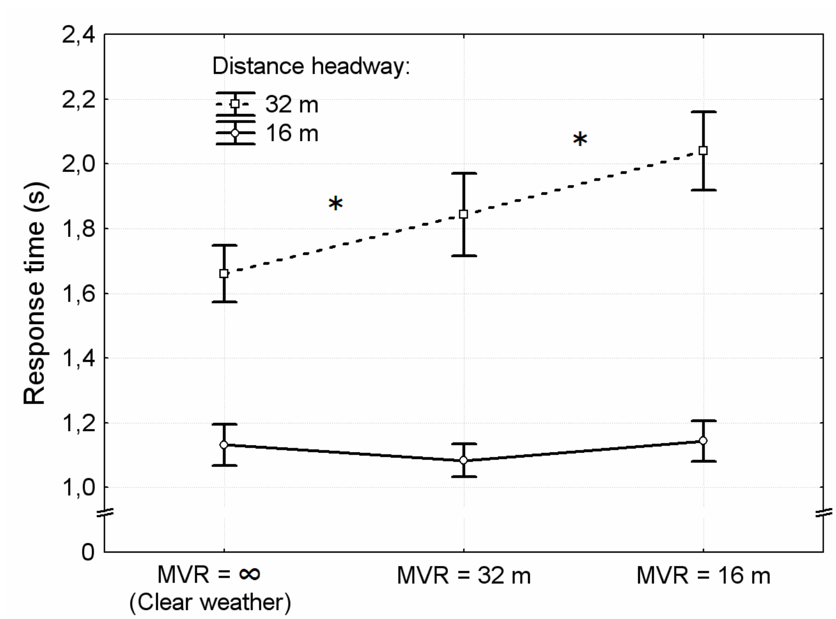

Figure 2. Response time as a function of meteorological visual range (MVR) and distance headway

Considering response times for a given fog density allows a better understanding from the driver's viewpoint. As shown in Figure 2, the reduction of response time when headway was reduced from 32 m to 16 m was greater with fog than in clear conditions. If we consider that collision risk increases when response time is longer and when headway is shorter, then the increase in risk when headway is reduced from 32 m to 16 m is lower in fog than in clear conditions. This means that the response time reduction in fog compensates more for the reduction in THW than under clear conditions.

PILOT STUDY

A pilot study was conducted in order to have more detailed results regarding distance headway so as to be able to quantify the change in response time for consecutive headway distances.

Method

Six subjects took part in the experiment. Apparatus and subjects' task were unchanged. There were six initial distance headways: 11.3, 16, 22.6, 32, 45.3, 64 m, and the only acceleration and deceleration rates used was 1.5 m/s^2. There were a clear weather condition and a fog condition with a 32-m meteorological visual range. Since only one fog density was used, the vehicle visibility in fog depended on distance headway. Then, the contrast between the vehicle outline and the background was, respectively, 34.7%, 22.3%, 12%, 5%, 1.5%, and 0.25%, such that the vehicle could only be seen by its fog lights for the longest headway.

Results

The pilot study showed no differences in reaction time between clear conditions and fog up to 22.6 m. This distance range corresponded to a good visibility of the lead vehicle outline, since its contrast with regard to the background was at least 12%. Longer response times in fog compared to clear conditions were found from 32 to 64 m. This distance range corresponded to poor visibility or no visibility of the vehicle outline, with a contrast less or equal to 5%. For this distance range, the increase in response times due to fog was on average 19.8% (0.39 s).

Response times were slightly lower for closing trials than for receding ones. Since we were interested in the collision risk with the lead vehicle, we focused on closing headway trials (Figure 3). We also calculated for closing trials the differences in response times for couples of consecutives distances. We hence obtained a response time gain associated with a given distance headway reduction (Figure 4). It appears that the response time gain seemed to be greater in fog than in clear weather only between 22.6 and 32 m, corresponding to a transient range of distances between a good visibility and a poor visibility of vehicle outlines (Figure 4). In other words, the perception and control benefit of driving closer in fog than in clear conditions seems to be limited to a small range of distances.

We hypothesized that under certain conditions a reduction in headway could lead to a response time gain as great as the considered THW reduction. Since the simulated speed was 50 km/h, the THW reduction corresponding to the five couples of consecutives distances were: 0.34, 0.48, 0.68, 0.96, and 1.35 s. It was higher than the corresponding response time gain, but the difference was not significant in fog conditions for the 22.6- to 32-m distance range. This means that within this last range of distances, closer following distances can be adopted in fog without necessarily increasing collision risk. Higher speeds or lower deceleration rates are expected to reinforce this result by reducing THW differences and increasing response time gain.

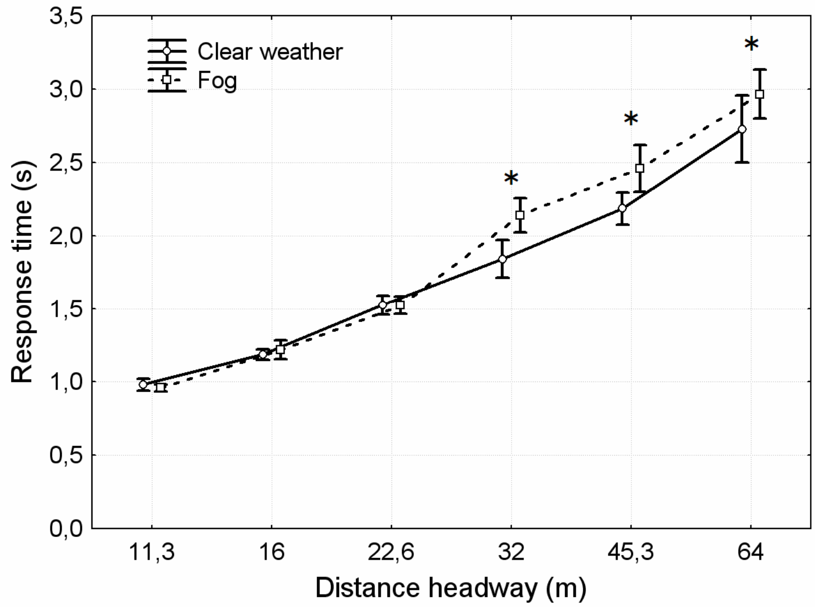

Figure 3. Response time as a function of distance headway for the pilot study, only considering closing headway trials

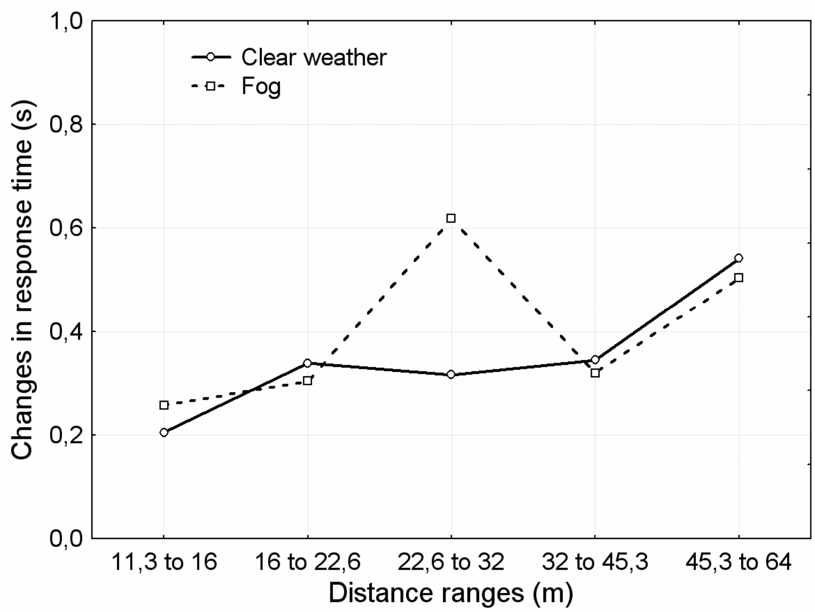

Figure 4. Changes in response time corresponding to a given distance range, only considering closing headway trials

CONCLUSIONS

The results suggest that driver's response times decrease more in fog than in clear conditions with decreasing distance, which means that the response time reduction in fog compensates more for the reduction in THW than under clear conditions. This suggests that driving closer in fog may have a perceptual-control benefit. The current experiments do show that within a limited range of following distances (i.e., 22.6 to 32 m) THW can be reduced in fog so that the reduction in THW is fully compensated by an equal reduction in response time. In other words, a closer following distance can be adopted without necessarily increasing collision risk. Doing so also benefits lateral trajectory control because the lead vehicle is less likely to be lost in the fog.

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