Safety Science 95 (2017) 50–61

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Driver behaviour in fog is not only a question of degraded visibility – A simulator study

F. Rosey *, I. Aillerie, S. Espié, F. Vienne

IFSTTAR-LEPSiS, 14-20 Boulevard Newton, Cité Descartes, Champs sur Marne, F-77447 Marne la Vallée Cedex 2, France

ARTICLE INFO

Article history:
Received 4 August 2014
Received in revised form 3 February 2017
Accepted 7 February 2017

Keywords:
Degraded visibility
Driver behaviour
Driving simulator
Road safety
Fog

ABSTRACT

The aim of this simulator study was to determine whether the effects of fog on driver behaviour were identical for a given road type and whether they could explain fog-related crashes according to road type. Thirty-three participants drove on both two-lane rural roads and motorways according to three visibility conditions (clear weather, 60 m-visibility and 30 m-visibility) and two driving situations (non-free driving and free driving). The variables were: Speeds (Ss), Headway Distances (HDs) and Headway Times (HTs). Fog was simulated using special software designed as part of the French Predit project VOIR, allowing both realistic vehicle headlights and halos to be displayed.

The results showed that the drivers decreased their speed with decreasing visibility distance, i.e., speeds were slower in the 30 m-visibility conditions than in clear conditions; but, speeds on the two-lane motorway remained faster than on the two-lane rural road, even for the denser fog. In the 30 m-visibility condition, the faster speeds driven on motorways than on two-lane rural sections violated those advocated by the French Highway Code. The distances travelled in conjunction with the speeds driven according to the two-second rule revealed that HTs less than 2 s and small HDs do not necessarily match with hazardous driving.

1. Introduction

Driving involves two different perceptual mechanisms: perception of absolute distance (obstacle-vehicle, vehicle-vehicle) and integration of obstacles or vehicles into the visual changes in the environment (road, vehicles and drivers). The task of driving requires timely detection of critical events and relevant changes in traffic circumstances, and the safety margins adopted reflect the amount of time drivers allow themselves in interacting with other road users and with the environment (Hulst van der et al., 1999). The driver must therefore solve a spatio-temporal problem mainly from visual information in a dynamic environment; this may make many aspects of visual input unpredictable. In order to anticipate future events, the driver must detect critical events and relevant changes in the driving environment in time, so that information processing leads to a decision adapted to the current driving situation. The importance of visual information is underlined by psychological research on perceptual processes which has shown that for the same road geometry, changes of surroundings influence driver perception (e.g., Bidulka et al., 2002; Bressan et al., 2003; Smith and Lamm, 1994; Vaniotou, 1990). It has also shown that roadway layout, road section alignment, and presence or lack of marking influence driver behaviour and may even lead to misperception of the road environment (e.g., Bressan et al., 2003; Fildes and Lee, 1993; Jansen-Osmann and Berendt, 2005; Vaniotou, 1990). This misperception can lead to crashes.

The problem of misperception of the road environment is increased in degraded driving conditions, such as fog and rain; the perception of absolute distance deteriorates and seems to be less direct than it is in clear weather conditions. Fog contributes to an increase in the difficulty for the driver of extracting from the road environment the visual information needed for safe driving (such as roadway layout, road section alignment), and visual information needed to anticipate future events because the driver cannot see as far ahead as he can in clear weather. The denser the fog, the harder the perception (Baumberger and Fluckiger, 2004). In foggy conditions, the driver's problem is to perceive the other vehicles, in order to drive safely in traffic.

In foggy conditions, both accident risk and severity of injuries increase, and multiple vehicle crashes are more represented than in clear weather conditions. Abdel-Aty et al. (2011), in a detailed look at fog- and smoke-related crashes in Florida (2003–2007)

* Corresponding author at: Cerema Normandie Centre, DITM-GESM, 10 chemin de la poudrière, CS 90245, F-76121 Le Grand Quevilly cedex, France.

E-mail addresses: florence.rosey@wanadoo.fr (F. Rosey), isabelle.aillerie@ifsttar.fr (I. Aillerie), stephane.espie@ifsttar.fr (S. Espié), fabrice.vienne@ifsttar.fr (F. Vienne).

http://dx.doi.org/10.1016/j.ssci.2017.02.004
0925-7535/

found that these crash types were most likely to occur during the winter months (December–February), in the early hours of the morning, and in rural areas. They also found that these crashes involve more vehicles and more serious injuries than did crashes in clear visibility conditions. From 1990 to 2012, the United States experienced a general decreasing trend in the number of fatal crashes involving fog (Hamilton et al., 2014). A study by Hamilton et al. (2014) showed that: (1) fog- and smoke-related crashes occur more in rural areas (nearly 2% of fatal crashes) than in urban areas (less than 1% of fatal crashes) and (2) undivided, two-way roadways see a greater share of fog- and smoke-related crashes than do divided or one-way roads. In France, this difference between road types also exists. On two-lane rural roads five accidents out of ten occur in foggy conditions; furthermore, in foggy conditions on motorways, the accident risk is multiplied by 1.3 (ONSIR, 2004). We performed an analysis on two years of crash data (2014–2015) from the French Road Safety Observatory (French acronym, ONISR) database. In this analysis we considered crashes involving two or more vehicles without pedestrians and in rural areas (i.e., undivided roads *vs* divided roads outside of urban areas.[1]) Furthermore, rear-crashes corresponded to collisions between only two vehicles; multiple pile-ups corresponded to collisions between two vehicles and more. This last crash type (in our analysis) was differentiated from multiple collision crashes (i.e., several collision types). The analysis showed, globally, that fatal crashes and deaths are more represented in clear weather conditions (6% and 70% respectively) than in foggy- and smoky-conditions (1.5% and 1.2% respectively). Fog- and smoke-related crashes are more represented on two-lane rural roads (72%) (i.e., in France, the majority of undivided roads) than on divided roads (28%) (i.e., in France, motorways and all others divided roads). In foggy and smoky conditions, fatal crashes and deaths represent 90% and 88% respectively on undivided rural roads; and 10% and 12% respectively on divided roads. Whatever the weather conditions, rear-crashes represent 20% of the total crashes; multiple pile-ups represent 7% and multiple collision crashes 10%. In foggy- and smoky-conditions according to road types these three crash types represent: 8% on undivided roads and 31% on divided roads respectively for rear-crashes; 3% on undivided roads and 26.5% on divided roads for multiple pile-ups and 12% on undivided roads and 19% on divided roads the multiple collision crashes. On undivided rural roads, deaths represent 6.5% for these three crash types. On divided rural roads, deaths represent: 0% for rear-crashes, 50% for multiple pile-ups and 25% for multiple collisions crashes respectively.

These crash data and statistics can be partly understood because in fog, speeds are often too high relative to the available visibility distances (Bulté, 1985; Hogema and Van der horst, 1994a), headway times decrease (Bulté, 1985; Hawkins, 1988; White and Jeffrey, 1980), and drivers underestimate their speeds (Snowden et al., 1998). Drivers reduce their speed in fog, but not enough to avoid a collision with a stopped vehicle or a slower vehicle ahead (Hogema and van der Horst, 1994b). Long-range visual information is needed to predict the path of the road ahead and to anticipate future events (e.g., Rumar and Marsh, 1998) and it allows better lane keeping (e.g., Summala, 1987). Absence of long-range information constitute a hazard since, during the daytime, drivers tend to stare further ahead rather than at the road edges (e.g., Serafin, 1994).

Furthermore, fog obviously increases an accident risk because the driver cannot see as far as in clear conditions, notably because it hides long-range visual information, then it degrades prediction of the path of the road ahead and anticipation of future events. This is understandable, since the perception of an object is not based on its absolute brightness or darkness, but on the difference between the object's brightness and the background. Fog substantially lowers contrast, causing objects to become fainter and less distinct (Green, 2004).

While many field and driving simulator studies (including some of the studies cited above) have shown how foggy conditions impact driver behaviour as demonstrated by their performance (e.g., speeds decreased, time headways decreased, etc.), they have usually been performed in a motorway context (e.g., Hawkins, 1988; Hogema and van der Horst, 1994a, 1994b; Moore and Cooper, 1972; van der Horst et al., 1993; White and Jeffrey, 1980) or on two-lane rural roads (Brooks et al., 2011).

The previous data reveal a different distribution of fog- and smoke-related crashes and of fatal crashes and deaths according to road types (i.e., undivided roads and divided roads). The aim of the present study was therefore to examine the impact of foggy conditions on driving behaviour according to two road types (i.e., two-lane rural roads and two-lane motorways) and according to two driving situations ("non-free" and free driving). The results may provide a better understanding of how drivers deal with available preview information when they look ahead, of how road types and/or driving situations impact this process, and may partly explain fog-related crash data.

The French Highway Code advocates headway times of 2 s for good visibility conditions, but fog restricts sight distance and distorts distance cues (as do the British and the American). From the different data taken together we expected that: (1) headway distances and headway times would increase with decreased visibility conditions, and that preferred speeds would decrease with decreased visibility conditions and (2) this behavioural adaptation would be greater in denser fog (i.e., 30 m-visibility condition) and in "non-free" driving situations. Furthermore, the French Highway Code requires that the speed must be 50 km/h on all roads when the visibility distance is less than 50 m. We expected that in the 30 m-visibility condition, the speeds driven would be identical and the two headways would increase on both two-lane rural roads and two-lane motorways sections.

2. Material and methods

2.1. Participants

Thirty-three participants with full French driving licences (i.e., not learners' or restricted licences) were recruited from an advertisement on *Relais d'information sur les sciences cognitives* (*RISC*) of *Centre National de la Recherche Scientifique* (*CNRS*). The participants were required to have had a driving licence for at least two years and needed to have normal or corrected-to-normal vision. Following an unforeseen technical problem, only 24 participants could experiment. One participant stopped because of sickness, leaving 10 women and 13 men ranging in age from 22 to 58 years (average age 35.5). Each participant was paid €60 for their participation. Upon their arrival in the laboratory, each participant was briefed on the requirements of the experiment and all read and signed an informed consent document.

2.2. Apparatus

The study was conducted using an INRETS-MSIS SIM2 driving simulator which is an interactive fixed-base driving simulator (Fig. 1). This is described in more detail elsewhere (Espié, 1999). The hardware is composed of four networked computers: one processes the motion equations and three generate the images. The data recording system acquired all the objective parameters (e.g.,

[1] In France, rural roads correspond to all roads outside urban areas (rural areas). Urban areas correspond to the zones between two road signs (entrance and exit) of a built-up area, whatever its size (ONISR, 2010).