



## **Influence of fog on driver behaviour using driver simulator. INTRO deliverable 4**

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Intelligent Roads

Project no. 012344

Specific Targeted Research Project  
Sustainable Surface Transport, priority 1.6.2

## D4.2 Integration of weather effects for traffic indicators forecasting

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Dissemination Level		
<b>PU</b>	Public	X
<b>PP</b>	Restricted to other programme participants (including the Commission Services)	
<b>RE</b>	Restricted to a group specified by the consortium (including the Commission Services)	
<b>CO</b>	Confidential, only for members of the consortium (including the Commission Services)	

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## 1 Influence of fog on driver behaviour using driver simulator <sup>1</sup>

### 1.1 Method

#### 1.1.1 Participants

33 drivers have participated. 9 have participated in the pre-experimentation. 24 have participated in the experiment *per se*. One participant has stopped due to sickness; thus remained 10 women and 13 men of ages ranging from 22 to 58 years (average age 35.5) and mandatorily having a driving license for two years at least. Each participant has been paid for his/her participation. The participants have been recruited through an announcement on INRETS website and through external contacts. The announcement stated that participants should not be sensitive to transport sickness, and they were advised to come by public transport.

#### 1.1.2 Material

##### The simulator

The study was conducted using INRETS-MSIS SIM<sup>2</sup> mini-driving simulator with a fixed-base, shown in Fig. 4.1. The simulator presented realistic three-dimensional driving scenes in panorama on three display screens (one in the center, and two on each side). Stereo speakers to the right and the left of the seat simulator provided road, engine and surrounding traffic noises. The driver controls consisted in a steering wheel, manual transmission, brake, and accelerator foot pedals. The simulated road surface was high friction corresponding to dry asphalt, and the scene visibility corresponded to clear daytime conditions



Fig. 4.1: Fixed-base mini-driving simulator.(c) 2007 MSIS INRETS

<sup>1</sup> Chap5 du D4.2 Integration of weather effects for traffic indicators forecasting (pp75-84).

The mini-simulator was equipped with a system with haptic feedback for the steering wheel and with a dynamic and interactive visual feedback. The virtual scene is displayed through three projectors on three displays, covering 150° of the driver's visual field and placed 2.80m away from the simulator cab.

The driving simulator provided auditory feedback regarding car speed, in the form of increased engine, road/pavement, aerolic noises with increased speed, of surrounding traffic noise (spatialised), and tactile feedback through the torque in the steering wheel.

### ***Fog simulation***

Fog is simulated using the library of effects as part of the VOIR project. The VOIR fog enables to simulate the dimming of contrasts and to restore the scattering effect of the light and of the light sources. It also enables to visualize the halo of the vehicle headlights and the produced fogging luminance by headlights, which are mandatory aspects to simulate road scenes (Cavallo, Dumont & Gallée, 2002).

## **1.2 Protocol**

As a first step, two questionnaires have been completed by the participants on their arrival: the first on the demographic characteristics and driving habits) and the second questionnaire has ensured that they do not have any vision problem, lastly a third questionnaire concerning their driving experience on simulator has been completed. The goal and the interest of these questionnaires have been explained to the participant every time. Moreover, an information form concerning the experience has been given to the subjects on their arrival.

As a second step, the participants were familiarized with the simulator on a neutral condition (section of motorway) until they acquired skills in simulator manoeuvring, before carrying out the experiment. The participants were informed that they will drive on secondary road following "others direction" signs until motorway. The simulation encouraged the participants to follow a pace maker vehicle, through a condition which prevented them to pass this vehicle, maintaining a safety distance with this reference vehicle. The participants had been informed that they will have to drive on motorway and secondary road at a speed adapted to the driving conditions, in order to follow or to pass the vehicles in the simulation. In order to make the following or passing situation as ecological as possible, the scenario (i.e. the manner which the other vehicles oncoming) encouraged every manoeuvre of the simulated vehicle (occurrence of road signals, of villages, of public works ...). The order of presentation of the situation (with or without fog) was: without fog, 60m of visibility and 30m of visibility.

The participants have been informed that some disturbances can occur during the simulation and that they will be able to stop the experiment at any time.

### ***Fog densities***

In driving under fog conditions, the most important independent variable is the distance of visibility. The study has been restricted to the day situations, for two reasons. First, Cavallo & al. (2002) have demonstrated that the simulation of fog by night was difficult. In particular, the perceptive differentiation between night conditions with and without fog is insufficient. Secondly, the behaviours by night may cause specific visual problems (Andreassend, 1970, Ackroyd & Bettison, 1970).

The 30m visibility condition allows the drivers to see the headlights and the silhouette of the vehicle that was 30m ahead. Thus for a greater distance the heading vehicle was only seen by its headlights. The 60m visibility condition allows the drivers to see the headlights and the silhouette of the vehicle that was 60m ahead.

## **Procedure**

Upon arrival at the laboratory, each participant had an initial briefing and signed the informed consent. Then the experimenter read the instructions verbatim while the participants were sit in the vehicle. In addition to a physical orientation to the apparatus and the expected task performance, participants were instructed to "Please drive like you would drive in the same situation in real" "You follow others directions, after when you see the announcement of motorway, take it" Until the visual message "Stop" or when notified "you can park on motorway hard shoulder".

## **1.3 Scenario**

The route consisted of two sections of 15 kms (secondary road and motorway section) with roundabout as junction. Each section of 15kms was composed to 3 segments of 5kms (one for each visibility condition). For each segment of 5 kms, participants drove in following condition for approximately 1km, near the end of this segment, the "lead" vehicle (here a car) slowed down in order to invite participants overtake it. Participants could overtake for approximately 1km. Near the end of this "overtaking" segment, if participants were no overtaken the "lead" car was draw into the side, thus participants drove again in following condition for approximately 1km, near the end of this segment, the "lead" vehicle (here heavy truck) slowed down in order to invite participants overtake it. Again one time, if participants were no overtaken the "lead" heavy truck was draw into the side ahead of the participant. For the secondary road section, both at 5km and approximately at 8km, participants were turned at left, near the end of the secondary road section, approximately at 14km participants were turned at right. After secondary road section, participants were negotiated a roundabout which permit them to go on motorway section. Data were collected in continuous during the 30 km realized.

Following condition was obtained with oncoming traffic from the contraflow lane for the secondary road section and with oncoming traffic from left lane for motorway. Overtaking condition was obtained by no oncoming traffic.

The "lead" vehicle was always at the maximal speed authorized according in the visibility conditions as it stipulated in the French's driving rules (i.e., 90km/h on secondary road and 130km/h on motorway in clear condition, 60km/h in 60m of visibility and 30km/h in 30m of visibility both for secondary road and motorway sections)

## **1.4 The variables**

In order to understand the influence of fog on drivers' behaviour we studied distances headway (DH, m), times headway (TH, s) and speed (S, km/h) were recorded. Indeed, in the frame of queuing or vehicle following the headway time characterizes the safety margin (i.e. the probability of unforeseeable decelerations of the vehicle ahead). Moreover, the time to collision characterizes the time available for the driver to achieve a manoeuvre in order to avoid a probable accident.

*Headway distance* (m) corresponded to distance from front bumper of participant vehicle to rear bumper of lead vehicle.

*Time headways* (s) corresponded to elapsed time between the moment the lead vehicle passes a given point and the moment the participant vehicle passes that point. Time headway was automatically calculated by a recording system. Data sampling rate was 30Hz.

To determine the fog impact on following and overtaking comparatively on clear conditions, we used a MANOVA analysis: the factors were "road type" (2 levels, secondary road and motorway with repeated measures), "visibility conditions" (3 levels, clear, 60m visibility and 30m visibility with repeated measures) and "driving action" (2 levels, following and overtaking). A pair wise post hoc analysis was carried out with planned comparison test. The threshold for statistical significance was set at .05.

## 1.5 Results

### 1.5.1 Mean speeds

MANOVA with repeated measures has shown a significant effect of road type [ $F(1, 22) = 315.75$ ,  $p < .0001$ ], a significant effect of driving action [ $F(1, 22) = 10.53$ ,  $p < .01$ , fig.6] and a significant effect of visibility conditions [ $F(2, 44) = 128.93$ ,  $p < .0001$ ]. Speed means on motorway were greater than secondary road, speed means during following action were lesser than during overtaking action whatever road type and speed means were greater in clear condition than in 60m of visibility, itself were greater than in 30m of visibility.

MANOVA has shown significant interactions

(1) Road type x Driving action [ $F(1, 22) = 14.46$ ,  $p < .001$ , fig.8]. Post-hoc analysis has shown that:

- on secondary road (SR) speed means between following and overtaking action were not significantly different [ $F(1, 22) = 0.40$ ,  $p = .53$ ] whereas on motorway, speed means during following were significantly lesser than overtaking [ $F(1, 22) = 18.17$ ,  $p < .001$ ].
- during following action speed means on secondary road (SR) were significantly lesser than on motorway [ $F(1, 22) = 134.05$ ,  $p < .0001$ ].
- during overtaking action speed means on secondary road (SR) were significantly lesser than on motorway [ $F(1, 22) = 368.81$ ,  $p < .0001$ ].

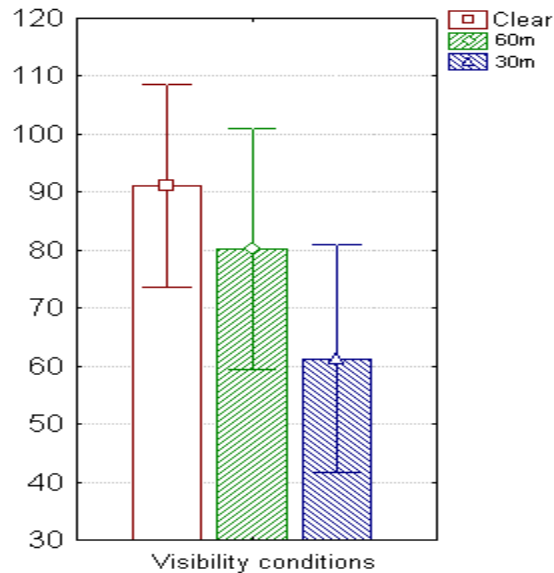
(2) Road type x Visibility conditions interaction [ $F(2, 44) = 4.58$ ,  $p < .01$ , fig.9]. Post-hoc analysis has shown that:

- on secondary road (SR) speed means in clear condition were significantly greater than in 60 m of visibility [ $F(1, 22) = 71.87$ ,  $p < .0001$ ] and in 30 m of visibility [ $F(1, 22) = 97.18$ ,  $p < .0001$ ]. Speed means in 60 m of visibility were significantly greater than in 30 m [ $F(1, 22) = 31.24$ ,  $p < .0001$ ]. On SR, speed means were greater in clear condition than in 60 m of visibility condition that was greater than in 30 m of visibility.
- on motorway (MW) speed means in clear condition were significantly greater than in 60 m of visibility [ $F(1, 22) = 6.17$ ,  $p < .02$ ] and in 30 m of visibility [ $F(1, 22) = 122.71$ ,  $p < .0001$ ]. Speed mean in 60 m of visibility were significantly greater than in 30 m [ $F(1, 22) = 104.02$ ,  $p < .0001$ ]. On MW, speed was greater in clear condition than in 60 m of visibility condition that was greater than in 30 m of visibility.
- on motorway (MW) speed means were significantly greater than on secondary road for all visibility condition (respectively; clear condition,  $F(1, 22) = 326.98$ ; 60m of visibility,  $F(1, 22) = 214.11$  and 30 m of visibility,  $F(1, 22) = 58.23$ ,  $p < .0001$ ].

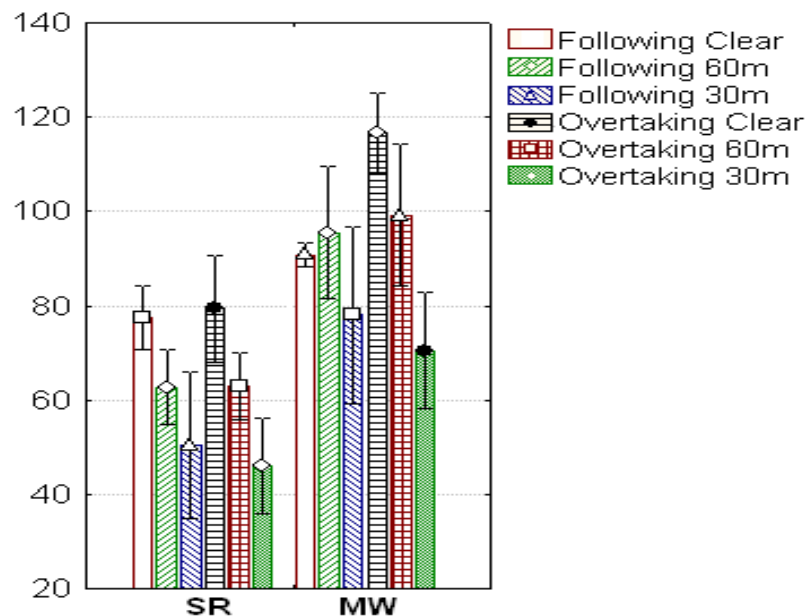
(3) Driving action x Visibility conditions interaction [ $F(2, 44) = 26.22$ ,  $p < .0001$ , fig.10]. Post-hoc analysis has shown that:

- during following action (Fo) speed means in clear condition were significantly greater than in 60 m of visibility [ $F(1, 22) = 6.60$ ,  $p < .01$ ] and in 30 m of visibility [ $F(1, 22) = 68.64$ ,  $p < .0001$ ]. Speed mean in 60 m of visibility were significantly greater than in 30 m [ $F(1, 22) = 56.65$ ,  $p < .0001$ ]. During following action, speed was greater in clear condition than in 60 m of visibility condition that was greater than in 30 m of visibility.
- during overtaking action (Ov) speed means in clear condition were significantly greater than in 60 m of visibility [ $F(1, 22) = 37.74$ ,  $p < .0001$ ] and in 30 m of visibility [ $F(1, 22) = 217.87$ ,  $p < .0001$ ]. Speed mean in 60 m of visibility were significantly greater than in 30 m [ $F(1, 22) = 120.82$ ,  $p < .0001$ ]. During overtaking action, speed was greater in clear condition than in 60 m of visibility condition that was greater than in 30 m of visibility.
- \*according to visibility conditions, in clear condition speed means during following were significantly lesser than during overtaking action [ $F(1, 22) = 84.71$ ,  $p < .0001$ ], in 60m of visibility they were not significantly different [ $F(1, 22) = 0.75$ ,  $p = .40$ ] and in 30m of visibility speed means during following were significantly greater than during overtaking [ $F(1, 22) = 12.25$ ,  $p < .002$ ].

The speed means according to visibility conditions and road type are presented in fig.4.2 and the speed means for each experimental condition are presented in fig.4.3



**Fig. 4.2: Speed means (km/h) according to visibility conditions and road type.**



**Fig. 4.3: Speed means (km/h) according to visibility, driving actions and road type. Secondary road (SR) and Motorway (MW).**



## 1.5.2 Mean time headway

MANOVA has shown that:

(1) Road type x Driving action interaction was not significant [ $F(1, 22) = 0.04$ ,  $p = .84$ ].

(2) Road type x Visibility conditions interaction was significant [ $F(2, 44) = 6.51$ ,  $p < .003$ , fig.9]. Post-hoc analysis has shown that:

- on secondary road (SR) times headway (TH) means in 60m of visibility were significantly greater than in clear condition [ $F(1, 22) = 10.68$ ,  $p < .003$ ] and than in 30 m of visibility [ $F(1, 22) = 446.07$ ,  $p < .0004$ ]. TH means in clear condition and in 30m of visibility were not significantly different [ $F(1, 22) = 0.19$ ,  $p = .66$ ]. On SR, TH means in 60m of visibility were greater both than in clear condition and 30m of visibility. TH means in clear condition and in 30 m of visibility were similar.
- on motorway (MW) headway times (TH) means in clear condition and in 60m of visibility were not significantly different [ $F(1, 22) = 2.77$ ,  $p = .10$ ], TH means in clear condition and in 30m of visibility were not significantly different [ $F(1, 22) = 1.56$ ,  $p = .22$ ] and TH means in 60 m of visibility and in 30 m were not significantly different [ $F(1, 22) = 2.36$ ,  $p = .14$ ]. On MW, TH means were similar whatever visibility conditions.
- on secondary road (SR) TH means were not significantly different that of on motorway (MW) in clear condition [ $F(1, 22) = 0.05$ ,  $p = .83$ ] and in 30m of visibility [ $F(1, 22) = 2.14$ ,  $p = .15$ ]. TH means in 60m of visibility were significantly greater on SR than on MW [ $F(1, 22) = 6.33$ ,  $p < .02$ ].

(3) Driving action x Visibility conditions interaction was significant [ $F(2, 44) = 8.26$ ,  $p < .0009$ , fig.10]. Post-hoc analysis has shown that:

- during following action (Fo) headway times (TH) means in clear condition were significantly lesser than in 60 m of visibility [ $F(1, 22) = 5.30$ ,  $p < .03$ ]. TH means in clear condition and in 30 m of visibility were not significantly different [ $F(1, 22) = 3.57$ ,  $p = .07$ ]. TH means in 60m of visibility and in 30 m of visibility were not significantly different [ $F(1, 22) = 2.99$ ,  $p = .10$ ]. During following action, TH means in clear condition were lesser than in 60m of visibility and TH means in 30 m of visibility condition were similar both to that in clear condition and in 60 m of visibility.
- during overtaking action (Ov) headway times (TH) means in 60m of visibility were significantly greater both than in clear condition [ $F(1, 22) = 6.98$ ,  $p < .01$ ] and in 30 m of visibility [ $F(1, 22) = 32.00$ ,  $p < .0001$ ]. TH means in clear condition and in 30 m of visibility were not significantly different [ $F(1, 22) = .001$ ,  $p = .97$ ]. During overtaking action, TH means in 60m of visibility were greater both than in clear condition and in 30 m of visibility, whereas TH means in clear condition and 30m of visibility were similar.
- according to visibility conditions, both in clear condition and 60m of visibility TH means during following were significantly lesser than during overtaking action (respectively,  $F(1, 22) = 21.48$ ,  $p < .0001$  and  $F(1, 22) = 9.29$ ,  $p < .006$ ) and in 30m of visibility TH means during following and during overtaking were not significantly different [ $F(1, 22) = 2.12$ ,  $p = .15$ ]

The times headway means according to visibility conditions and road type are presented in fig. 4.4 and the speed means for each experimental condition are presented in fig. 4.5



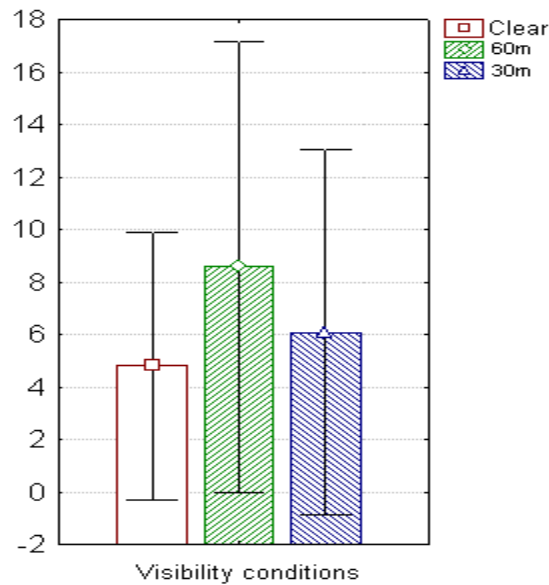


Fig. 4.4: Times headway means (s) according to visibility conditions and road type.

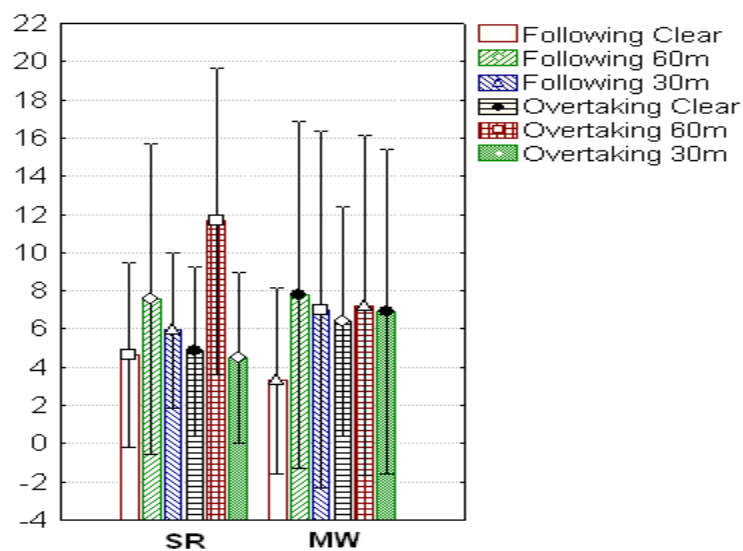


Fig. 4.5: TH means (s) according to visibility, driving actions and road type. Secondary road (SR) and Motorway (MW).

### 1.5.3 Mean distance

MANOVA with repeated measures has not shown a significant effect of road type [ $F(1, 22) = .02$ ,  $p=.90$ , fig.12], but a significant effect of driving action [ $F(1, 22)= 9.39$ ,  $p=.01$ , original  $p=.005$ , fig.13] and a significant effect of visibility conditions [ $F(2, 44)= 10.80$ ,  $p<.0001$ , fig.14]. Distance headway means on motorway were similar to that secondary road. DH means during following action were lesser than during overtaking action whatever road type and DH means in 60m of visibility were greater than both in clear condition and in 30m of visibility. Distance headway means in clear condition were greater than in 30m of visibility.

MANOVA has shown that:

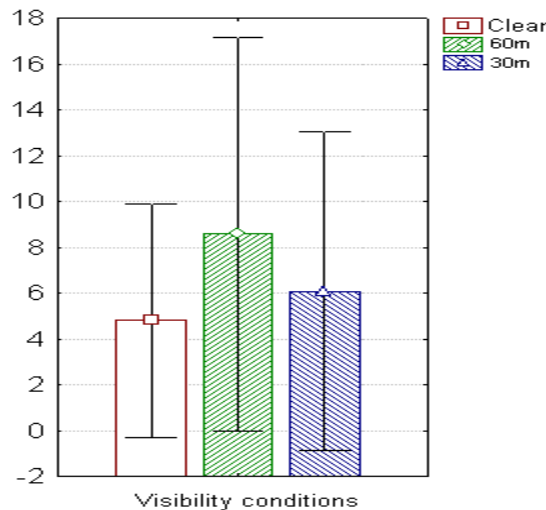
(1) Road type x Driving action was not significant [ $F(1, 22)= (1, 22)=.86$ ,  $p=.36$ ].

(2) Road type x Visibility conditions interaction [ $F(2, 44)= 2.04$ ,  $p=.14$ ].

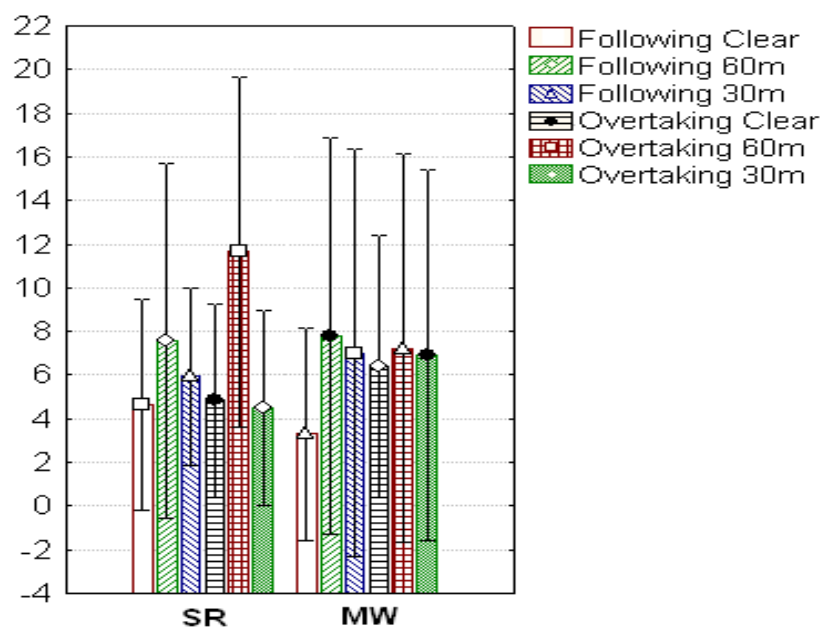
(3) Driving action x Visibility conditions interaction [ $F(2, 44)= 3.82$ ,  $p<.03$ , fig.10]. Post-hoc analysis has shown that:

- during following action (Fo) distance headway means in clear condition and in 60m of visibility were not significantly different [ $F(1, 22) = 2.18$ ,  $p=.15$ ] and distance headway means in clear condition and in 30m of visibility were not significantly different [ $F(1, 22) = 0.21$ ,  $p=.65$ ]. DH means in 60 m of visibility and in 30 m were not significantly different [ $F(1, 22) = 3.55$ ,  $p=.07$ ]. During following action, distance headway means were similar whatever visibility conditions.
- during overtaking action (Ov) distance headway means in clear condition were significantly greater than in 60 m of visibility [ $F(1, 22) = 7.31$ ,  $p<.01$ ] but they were not significantly different of that in 30 m of visibility [ $F(1, 22) = 4.07$ ,  $p=.055$ ]. DH means in 60 m of visibility were significantly greater than in 30 m [ $F(1, 22) = 25.90$ ,  $p<.0001$ ]. During overtaking action, DH in 60 m of visibility condition was greater than both clear condition and in 30 m of visibility. Furthermore, DH in clear condition and in 30 m of visibility were similar.
- according to visibility conditions, clear condition DH means during following and during overtaking action were not significantly different [ $F(1, 22) = 4.17$ ,  $p=.053$ ], in 60m of visibility DH means during following action were significantly lesser than during overtaking action [ $F(1, 22) = 8.89$ ,  $p<.01$ ] and in 30m of visibility headway means during following and during overtaking action were not significantly different [ $F(1, 22) = 0.06$ ,  $p=.81$ ]. Distance headways during following and during overtaking action were similar both in clear condition and 30m of visibility. Distance headways during following action were lesser than during overtaking action in 60m of visibility.

The distance headway means according to visibility conditions and road type are presented in fig. 4.6 and the speed means for each experimental condition are presented in fig 4.7



**Fig. 4.6: Distance headway means (m) according to visibility and road type**



**Fig. 4.7: TH means (s) according to visibility, driving actions and road type. Secondary road (SR) and Motorway (MW).**

## 1.6 Discussion

### 1.6.1 Speed

It is the visibility conditions which influence differently speed according to driving action. In clear condition, drivers follow with lesser speed than when they overtake. In 60m of visibility, they follow and overtake with similar speeds, whereas in 30m of visibility they follow with speeds greater than when they overtake. The fact that the speed means were lesser during overtaking than following action in 30m visibility condition can be explained by the fact that when drivers follow in 30m of visibility they have visual frame with vehicle immediately above whereas when they overtake they lost this visual frame. The influence of visibility "lead" vehicle was always at the maximal speed authorized according in the visibility conditions as it stipulated in the French's driving rules (i.e., 90km/h on secondary road and 130km/h on motorway in clear condition, 60km/h in 60m of visibility and 30km/h in 30m of visibility both for secondary road and motorway sections).

### 1.6.2 Time Headway

Drivers drive with similar headway times on secondary road and on motorway whatever driving action (i.e., following and overtaking). It is again with the visibility conditions that the differences appeared. Indeed, drivers drive with greater HT in 60m of visibility both in clear condition and 30 m of visibility, but they drive with HT lesser in clear condition than in 30m of visibility. Visibility conditions have more impact for secondary road section than motorway section. Drivers drive with HT greater in 60 m of visibility than in clear condition and in 30 m of visibility. They drive with similar HT in clear condition and in 30 m of visibility. Whereas on motorway drivers drive with similar HT in the three visibility conditions. If the headway times means are greater than that is advocated by driver's manuals (2 or 3 s for a traffic safety), they were contained by 0.27-18.28 for the lesser range (30m of visibility on secondary road) and 1.06-31.23 for the greater range (clear condition motorway). Headway times variability seems to show that the driver certainly use different strategies according to visibility conditions.

### 1.6.3 Distance Headways

Drivers drive with similar distance headway on secondary road and on motorway that is throw the problem that for a same distance headway drivers drive speedier on motorway than on secondary road. Drivers overtake with greater distance headways than when they follow cars. Drivers drive with greater distance headways in 60m of visibility than both in clear condition and 30 m of visibility, and they drive with greater distance headways in clear condition than in 30m of visibility.

## 1.7 References

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