# BENEFITS OF A MOVING POINT-OF-LIGHT (POL) AS A MEANS TO MAINTAINING SAFE HEADWAYS IN TUNNELS

By

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# **OBJECTIVE**

The objective of this study was to evaluate a new technology to maintaining headway while driving in tunnels. With this system a beam of light is projected on the wall of the tunnel at *a fixed distance behind each vehicle*. The role of each driver, then, is to simply stay behind the moving Point-Of-Light (POL) that is projected for the vehicle ahead, thereby assuring a safe headway. Specifically this technology was evaluated relative to existing aids to maintaining headway and the benefits were evaluated in terms of the (1) the actual headways the drivers maintained with the POL in comparison to other more traditional systems, and (2) the attentional load on the driver that the POL has relative to the other systems.

### BACKGROUND

In the second half of the past century, innovations in technology enabled the construction of very long tunnels in many parts of the world. Driving in a long tunnel is not equivalent to driving on the open road. This is because the driver is confined to a dark closed environment for a long period of time. This environment may impair the performance of drivers, which in turn can lead to serious consequences. Accidents in road tunnels, and especially accidents involving fires, are one of the biggest threats. This is because heat and smoke can spread quickly within the confines of the tunnel (having nowhere else to spread) and their effects can be lethal. Human behavior plays a crucial role in the initiation, development, and consequences of accidents. Giving the driver more time to think and react, will improve his performance in an emergency and will help him or her avoid a sudden incident ahead of him.

One simple method of providing the drivers with more time to respond to emergencies is by forcing them to drive slowly and to maintain longer-than-usual headways to the vehicle ahead. For example, in the 13 km long Frejus Tunnel that connects Italy and France, this philosophy has led to a recommendation to drive at 70 km per hour and maintain a headway of 150 meters. While all drivers have speedometers that enable them to maintain a certain speed, there are no such devices (headometers?) are currently installed on all vehicles to provide drivers with feedback on their headways.

This raises a few questions that are addressed below:

- 1. How good are drivers in maintaining headways? The required headway is extremely long relative to standard recommendations, since at 70 km/hr it implies a time headway of 7.7 seconds, versus the generally recommended 2 seconds, and the actual 1 second that is often observed on the highways (Ben-Yaacov, Maltz, and Shinar, 2001; Chen, 1996; Evans and Wasielewski, 1983; Shinar and Schechtman, 2002).
- 2. If drivers are not good at such a task can it be easily learned with proper feedback?
- 3. Is there a difference between the headways that drivers keep and their verbal estimates of these headways?
- 4. Is there an attentional cost to maintaining a pre-determined headway?

#### Our ability to Perceive Headway

The term used to indicate the distance between consequent vehicles, is distance Headway (DHW) or Time Headway (THW) (Fuller, 1981). DHW is defined as the distance between bumpers of the leading and following cars.

THW is defined as the time between two cars, and it is calculated as:

$$THW = \frac{DHW}{Speed (Following Vehicle)}$$

Studies of human distance perception have shown that the relationship between actual distance (d) and judged distance (d) is well described by Stevens' power law:  $\delta = k \cdot d^n$  where the modulus k is a unit-dependent scale factor and the exponent n depends on the nature of the judgment (Stevens, 1975). A more natural and often used measure of accuracy is the percentage of overestimation:

% Overestimation = 
$$\frac{100(\delta-d)}{d}$$

Most studies of human distance perception have focused on modeling distances between an observer and an object (rather than between two objects). These studies generally yield exponent estimates very close to one; however, the exponent can range between 0.8 and 1.1 depending on the nature of the estimation task and the properties of the viewing environment (Wiest and Bell, 1985). Most studies find that in natural settings, distances from 3 to 90 meters are typically underestimated and yield exponents between 0.91 and 1.00 (Wiest and Bell, 1985).

In the context of driving, in the absence of other cues, the size of the retinal image of the lead vehicle is the best cue that the following driver has concerning its distance. This is because pictorial cures such as relative size are among the strongest cues to depth perception (Levine and Shefner, 1991). However, as the distance increases, the perceived size of the lead car decreases non-linearly (Mortimer, 1990). Thus, when a leading vehicle is far ahead, the rate of size change is less than when it is close. Hence the bigger the distance between two cars, the more difficult it will be for the driver to keep and maintain a constant time headway. Since drivers base their closure rate judgments heavily on changes in visual angle, they often derive little information on the velocity of the lead vehicle or the relative velocity between vehicles (Mortimer, 1988). Several studies that examined drivers' abilities to either estimate headways or produce specific headways showed that they actually overestimate their headway, so that productions of headway are actually shorter than required (Ben Yaacov, Maltz, and Shinar, 2002; Ohta, 1994; Taieb and Shinar, 2001; Van Winsum and Heino, 1996), thus creating situations in which drivers believe that they safer than they really are. An additional concern is that in all of the above studies the time headways involved were typically 1-2 seconds, which at speeds of 100 km/hr involve distance headways of 55 meters. In contrast, in the Freijus tunnel drivers are required to keep a headway of 150 meters (at 70 km/hr this is equivalent to 7.7 seconds), which is much more difficult to judge, given the smaller variations in the retinal image of the vehicle ahead.

# Learning to Keep Headway

Learning is a known process of experience and feedback. Typical learning curves are characterized by logarithmic functions, which mean that the improvement rate diminishes after a certain level of practice (Fitts and Posner, 1967). Although Drivers practice headway-keeping on a daily basis, they do not receive any feedback for it. Therefore it is reasonable that the verbal estimates of drivers will not be exact, but after getting enough feedback they should show an improvement in their estimates.

Studies that examined improvement in headway estimation after receiving feedback are rare. Groeger, Grande and Brown (1991) examined how different learning methods influence improvement of time to arrival to a certain point. They used films, which were shot from a car going towards a junction. The films stopped at different times before arriving at STOP signs. The training methods included several kinds of feedback on the estimation error: (1) distance in feet, (2) time in seconds, and (3) speed in km/h. Improvement in time-to-arrive estimates was found only for the distance and time feedbacks. Before receiving the feedback there was a mean underestimation of time-to-arrival, which got smaller as the films stopped closer to the junction. Taieb and Shinar (2001) compared three methods of learning to estimate headways correctly: one based on time (seconds), and two based on distance (meters and cars). The learning process was very fast with all three methods, and after one trial with feedback the estimations improved substantially and the variance got smaller. A later study by Ben Yaacov, Maltz, and Shinar (2002), confirmed these findings and also showed that once learned, these headway estimation abilities can be retained for a long time – six months in the case of that particular study!

One method to improve headway judgments is to give drivers visual anchors, explanations and depth clues. An example of such depth clues are equi-distant markings across the road (as done on the French motorways), or equidistant markings on the walls of tunnels, with distance indicators that are appropriate for the speeds typical for that road. On the other hand, if the open-road results with short headways are also applicable to the longer headways in tunnels, then headway judgments can be quickly learned with cues that are provided only in the entrance to the tunnels. No data currently exist to resolve this, and this study is designed to address these possibilities.

#### Verbal Estimates versus Non-Verbal Responses

The results of many studies indicate that when there are sufficient depth clues such as size and object constancy, the distance perceived is very similar to the actual distance (Sedgewick, 1986). However, when some of these distance cues are missing (e.g. in the desert or at night), the quality of judgment deteriorates substantially (Landauer and Epstein, 1969). In a moving vehicle the task becomes harder and the number and types of depth cues available change uncontrollably, at each moment.

While trying to establish, whether drivers are able to evaluate headways properly or not, we should distinguish between verbal and non-verbal estimations. Different studies showed that in many cases subjects were able to make appropriate distance judgments even though the visually processed information was not verbally accessible (Leibowitz, Guzy, Peterson, and Blake, 1993). Thus, pedestrians can determine quite accurately when it is safe to cross the street without knowing the exact values of the road's width, the vehicles' distance and speed, and their own walking speed (Lee, 1976). Similarly, while engaging in a car following task, it is possible that a driver will be able to successfully accomplish the non-verbal task of maintain a safe distance from a lead car, but will not be able to give an accurate numerical value to the distance from that car.

The verbal estimation of headway is very important in car following, because the instructions given to drivers are often in the verbal form. For example licensing booklets instruct drivers to keep headways of 'two seconds', and at the entry to the Frejus tunnel a variable message sign instructs drivers to maintain headways of 150 meters. It appears that the method used to estimate headways – time, meters, or car-lengths – affects the accuracy of the estimates. According to Taieb and Shinar (2001), accuracy is higher when the estimates are in meters and carlengths than when it is given in the seconds. However, in their study the variance in estimations, was the smallest when their drivers estimated headway in terms of car lengths and largest when they estimated the headway in seconds. One possible reason for the advantage of the car-lengths method is that while driving, the drivers often see other cars on the road and these cars can serve as recurring benchmarks. With the meters and seconds methods, the scale depends on memory and is therefore prone to the typical shortcomings of absolute judgments.

#### **Driving and Workload**

In order to compensate for high task demands in complex hierarchical tasks, operators often resort to different strategies that give different values to different aspects of the complex task (Bainbridge, 1974; Hockey, 1993, 1997). One strategy is to invest more effort in the task. Another strategy is to adopt less demanding work strategies, which involve fewer manipulations of information or less use of working memory, or adopt a more relaxed method of work (working more slowly or less accurately). A third strategy is to skip subsidiary tasks that are not essential for performing the main task. The effect of this last strategy is an increased focus on the main task, at the expense of subsidiary tasks (Hockey, Wastell and Sauer, 1998). According to Hockey (1997) overall task performance may decrease when less demanding strategies are used or subsidiary tasks are skipped, but the primary task goal is usually protected against degradation.

Driving is one example of a complex dynamic task. Already in the 1960s the driving task was described as a selfpaced task (Taylor, 1962), where drivers change their behavior in response to secondary task demands. For example, Brown and Poulton (1961) and Brown (1962) showed that performance on a secondary auditory task deteriorated when demands of the primary driving task increased. Later studies confirmed these results and found evidence for a number of strategies in dealing with high task demands, most notably a change in driving behavior and neglect of a subsidiary task. For example, Harms (1991) found that in demanding traffic situations both strategies were used: drivers decreased their driving speed *and* were slower in responding to a mental arithmetic task. Other studies have also shown that car drivers adopt less demanding strategies by changing their driving behavior when task demands increase. Drivers reduced their driving speed when task demands increased (e.g., Cnossen, Meijman and Rothengatter, 2000; Dingus et al., 1997; Pohlman and Traenkle, 1994), and increased their headways when they had to monitor an in-vehicle display while driving (Noy, 1989). Car drivers also neglect subsidiary activities when task demands increase. For example, various studies have found that participants tend to check their rear-view mirror less with increased task demands, such as when driving with a visual route guidance system or when performing additional memory tasks (Landsdown, 1997; Fairclough, Ashby and Parkes, 1993; Brookhuis, De Vries and De Waard, 1991). Taken together, driving can be a demanding task, and the need to attend to headway cues may place additional demands that may reduce driving efficiency. Thus, any method of providing drivers with headway cues, should also consider the attentional loads that it places on the driver.

In light of the present knowledge about drivers' abilities to estimate headways, and especially given the extremely long headways recommended in tunnel driving, it was impossible to predict the benefits of an innovative point-of-light system, relative to more traditional methods, such as equi-distant lines painted along the tunnel walls. Therefore, this tunnel driving simulation study was designed to evaluate 3 methods for keeping the desired safe headway of 150 meters, relative to a control condition consisting only of verbal instructions. The three methods were:

- 1. Repeated line markings on the road. Equi-distant lines were marked on the tunnel wall every 50 meters and the driver had to maintain a gap of 4 lines behind the lead car.
- 2. Same as above but the repeated line markings extended only for the first two kilometers. This approach was tried on the basis of the results of Taieb and Shinar (2001), who found that drivers learn to estimate headways rather quickly.
- 3. Moving point-of-light (POL). In this innovative method an diamond-shaped image was projected on the wall of the tunnel at a constant distance of 150 meters behind each vehicle and the following driver had to remain slightly behind the image and not pass it.

# METHOD

# Apparatus

A fixed base driving simulator was used in the study, and it consisted of two components: A computer software package "STI-SIM", manufactured specifically for driving research by Systems Technology, Inc. and the cab of a Seat Malaga in which the driver was seated when 'driving' the simulator. The simulator environment is depicted in Figure 1. In the simulator the driver has interactive controls of the steering wheel and the brake and accelerator pedals the gears are automatic. The roadway is displayed on a wide screen that located in front of the car and provides the driver with a true 40-degree horizontal field of view (i.e., 1:1 scale).

Figure 1. The Ben Gurion University Driving Simulator, with the vehicle and 40-degree screen.



# **Tunnel Specifications**

The experiment included driving through a tunnel with dimensions identical to those of the Frejus tunnel. The tunnel is a two-directional road with two 3.55 m-wide lanes, a total width of 10.00 m, a height of 4.5 m, and shoulders of 1.00 m one each side. To vary the difficulty of the drive, the number of curves in the tunnel was varied. The simplest, least difficult, tunnel resembled the Frejus Tunnel most closely. It had two curves at the two ends of the tunnel with radii of 500 m each and 3 additional shallow curves with a radius of 2000 m each. The second level of difficulty included 10 curves - 4 with a 500 m radius and 6 with a 2000m radius. The most difficult level included 20 curves - 8 with a 500 m radius, and 12 with a 2000 m radius. The length of the Frejus tunnel is nearly13 km, but in the present study the tunnel varied from 12 to 15 km. The actual distance the subjects drove under different experimental conditions varied, because they had to drive for10 minute periods at 70, 80, and 90 km/hrs. Thus, the actual driving experience varied from 11.7 km at 70 km/hr to 15 km at 90 km/hr.

# Subjects

The subjects were 48 licensed drivers ranging in age from 22 to 35, with at least 5 years of driving experience, and visual acuity of 6/9 or better in both eyes.

### **Experimental Design**

A Between-Subject Factorial design with partial repeated measures was used. The subjects were divided into 4 groups (1 control and 3 experimental) as follows:

- 1. Control group: Subjects were instructed to keep a distance of 150 meter from the car ahead (as they currently are in the Frejus Tunnel), without the benefit of any aids to estimating the headway.
- 2. 2 KM equi-distant lines For the first 2 kilometers Subjects drove next to painted white lines marked on the tunnel right wall every 50 meters. They were told that the lines are 50 meters apart, and they were instructed to keep a safe distance of 4 lines (150 meters) behind the car ahead of them. The lines ended at the end of the second km and the subjects were told to keep the same distance behind the front car but without the aid of the lines.
- 3. Total trip equi-distant lines Subjects in this group had the lines every 50 meters throughout their drive from the beginning to the end of the tunnel. As for group 2, they were instructed to keep a 4-line gap (150 meters) from the lead car.
- 4. Moving Point of Light (POL) The subjects saw a dynamic diamond to the right and in front of them. The object was a black rectangle with a light colored diamond shape painted on it. The diamond was placed 150 meters behind the lead car on the tunnel wall above the right shoulder, and moved alongside the tunnel wall (see Figure .2). The subjects were instructed to adjust their speed so that the diamond remained at a constant position in their right visual field.



Fig. 2 The moving Point-of-Light

In addition to the Road Type, which was manipulated between subjects, three independent variables were manipulated within-subjects:

- 1. Mean speed of the lead car (70, 80, and 90 km/hr),
- 2. Tunnel difficulty (5, 10, or 20 curves), and
- 3. Tunnel vs. open road driving.

Driver performance was evaluated on the basis of three dependent variables:

- a. Mean headway
- b. Standard deviation of the headway
- c. Number of secondary task signals missed (used to measure attentional workload).

### Procedure

Each subject started the session with an explanation about the goal of the study (i.e., keep the required headway), and about the vehicle controls. At the end of this stage, the subjects drove in simulated tunnel environment for a period of 10 minutes (without recording their performance) in order to adjust to driving the simulator and to minimize a learning curve effect.

After the initial learning session, the measurement began in the simulated tunnel. Each subject drove twice on an open road and three times through the tunnel - each time was considered a *trial* - under the following conditions:

- 1. Easy tunnel 5 curve with a radius of 500m, a rough simulation of Frejus tunnel (see tunnel specifications).
- 2. Moderately difficult tunnel -10 curves (see tunnel specifications).
- 3. Difficult tunnel 20 curves (see tunnel specifications).
- 4. Open Road The subjects drove through an open road that was geometrically identical to the difficult tunnel, for a total of 10 minutes. This was done, in order to see if there is a difference in driving behavior between the tunnel and the geometrically similar open road,

In each trial, the subjects were instructed to follow a truck, moving at one of the following speeds:  $70 \text{ km/hr} \pm 5 \text{km/hr}$ ,  $90 \text{ km/hr} \pm 5 \text{km/hr}$ , and  $110 \text{ km/hr} \pm 5 \text{km/hr}$ .

The total time of each trial was 10 minutes, allowing the subjects to drive 3.33 minutes at each speed. The order of the trials and the order of the speeds within trial were counterbalanced across subjects in each group. The order the car to be followed (with different speed) in each condition was also counterbalanced.

At the end of the 10 minutes practice period, all subjects drove on the open road for five minutes before driving through the tunnel, and then again for five more minutes after finishing the drive through the tunnel. The reason for splitting the drive on the open road was to minimize fatigue and learning effects.

# Subsidiary task

In all 12 conditions (4 Road Types X 3 Speeds) the driver had to perform a subsidiary task. The task involved 3color display of lights on the car's dashboard - green orange, and red – with a response button under each light. The task was to press the button as quickly as possible whenever the light above it was turned on. The lights were activated at random intervals with a minimum of 5 seconds and a maximum of 16 seconds between two consequent lights. Reaction time to the light was measured, and whenever no reaction occurred within 2 seconds the trial was coded as a 'miss' (incorrect answer).

# RESULTS

The effects of guidance method (POL, 2 km markings, repeated markings, control), speed (70, 90 and 110 km/hr) and road type (easy tunnel, moderately difficult tunnel, difficult tunnel, and difficult open road) on how well drivers kept the 150-meter required headway, were examined with a three-way, repeated measures, analysis of variance (ANOVA). The dependant measures were: average headway between cars, and standard deviation of the headway between the cars. The ANOVA was performed twice, once per each dependant measure.

# **Average Headway**

The average headways and between-drivers standard deviations of the average headway at each of the three speeds are presented in Table 1. The analysis of variance showed that although the drivers were instructed to maintain the same distance headway at all speeds, the speed significantly affected the headway, F(2, 42)=13.197, p<0.001. Tests of contrasts showed that the effect was due to a significant difference between the headway at 110 km/hr and the two slower speeds, which did not differ from each other.

Table 1.	Average Distance	Headway as a	Function of the	Speed of the Lead Car
	0	•		•

Headway \ Speed	70 km/hr	90 km/hr	110 km/hr
Mean Headway	202.94	201.66	232.04
SD of Headway	74.63	74.81	114.49

The headway guidance method also had a significant effect on the average headway, F(3, 43)=9.41, p<0.001. A post hoc LSD test showed no difference between the moving POL and the repeated line markings group, but both groups kept significantly shorter headways, *which were much more consistent with the required headways*, than the drivers in the control condition and in the 2-km lines condition. The average headways, and the between-drivers standard deviations of the headways in each condition, are provided in Table 2.

Table 2. Distance Headway and Between-Subjects Standard Deviations of Distance Headways (in Meters) as
a Function of the Headway Guidance Method

	Control	2-km Line	Repeated Line	Moving Point
	Condition	Markings	Markings	of Light
Average Headway	247.82	269.97	187.30	163.43
Standard Deviation	128.25	86.75	43.57	24.89

Though the difference in the average headway between the moving point of light and the repeated lines groups was not significant, there is a noticeable difference in the variance (SD=43.57 in the repeated line vs. SD=24.89 in the POL), indicating that with the moving POL the variability among drivers is minimal, being  $1/5^{th}$  of the variability (in SD units) when no headway cues are provided at all. The effectiveness of the POL in reducing headway to the desired level is apparent from Figure 2.

The effectiveness of the headway guidance method was also influenced by the speed. There was also a significant interaction between guidance method and speed, F(6, 86) = 3.91, p<0.001, and, as can be seen from Figure 3, it was due to the fact that while with all guidance methods headway increased slightly with speed, when no supplementary headway cues were provided at all (i.e., the control condition) drivers increased their headways by nearly 30% when they moved from the lower speeds of 70 and 90 km/hr to the highest speed of 110 km/hr.



Figure 2. The effects of the Headway Guidance Method and Speed on the Mean Headway

The effect of the road type was significant only in its interaction with the average speed, F (6, 38) =4.029, p<0.003. There were no consistent differences in headway between the different road types, but at the high speed of 110 km/hr, headways was significantly longer in the simple, least difficult, tunnel than in all other road types including the open road.

#### Standard Deviations (within Drivers) of the Headway

In addition to the examination of the between-drivers variability, it is also important to examine the within driver variability in order to assess the stability of the following distance each driver maintains. The greater the variance, the lesser the stability, and the greater the risk of an accident. The analysis of the within-drivers variability in maintaining headway was evaluated with a 3-way analysis of variance. The results showed that the variability in headway was significantly affected by all three factors: the road type, the lead car speed, and – most importantly – the headway guidance method.

The significant effect of speed, F(2, 42)=9.34, p<0.001, is shown in Table 3, from which it can be seen that as the speed increased so did the headway-STD. Tests of contrasts showed that all average headways at all three speeds were significantly different from each other.

# Table 3. Within-driver Standard Deviations of Headway (Headway-STD) as a function of the Lead Car's Speed

	70 km/hr	90 km/hr	110 km/hr
Headway-STD	40.64	48.19	51.10
SD	24.25	33.89	34.01

The Road Type also affected headway-STD significantly, F(3, 41)=6.87, p<0.001. Tests of contrasts showed that the effect was due to greater headway variability on the open road than on all three tunnel types. The mean headway-std for each road type is presented in Table 4.

#### Table 4. Standard Deviation of Distance Headway as a function of Tunnel Type

	Simple	Moderate	Difficult	Open Road
Headway-STD	46	42	47.3	50.8
SD	30.8	29	37	26.8

The headway guidance method had a very strong effect on the variability in headways, F(3)=14.6, p<0.001. A post hoc Scheffe test showed that the moving POL yielded significantly smaller variability than the other guidance methods: repeated line markings p<0.004, control, p<0.002, and the 2 km line markings p<0.001. The results are displayed in Table 5.

#### Table 5. Standard Deviation of Distance Headway as a function of Guidance Method

	Control	2 km line	Repeated Line	Moving Point
	Condition	Markings	Markings	of Light
Headway-STD	51.2	62.9	46.1	24.3
SD	27.9	41.3	18.2	17.6

The effect of the headway guidance method on headway variability was also significant in its interaction with road type, F (3, 43) = 8.15, p<0.001, and speed, F(3,43)=8.61, p<0.001. No consistent pattern was observed in the first interaction, but the second interaction is represented in Figure 4. From this figure it can be seen that the interaction is due to the fact that the 2-km lines are actually worse than no cues at all (control) at all but the lowest - 70 km/hr – speed.

# Learning to Estimate Headway

The rationale for using the 2-km lines - based on some of our past research with shorter headways of up to 55 m - was that with good feedback drivers can quickly learn to estimate the headway correctly and then maintain it without the use of any supplementary cues (Taieb and Shinar, 2001; Ben-Yaacov, Maltz, and Shinar, 2002). We therefore thought that we would find no differences in headways between the full distance repeated line markings

method and the 2 km line markings. However, the results did not support this hypothesis, and showed that the fulldistance line markings are superior to the 2-km line markings. To verify that the difference between the two methods was not due to some inherent difference between the two groups, we compared their performance *in the first two kilometers only*. A t test of the difference in the mean headway of the two groups in the first two km only, showed that the two groups did not differ significantly from each other.





#### **Cognitive Load: Performance on the Secondary Task**

Cognitive load was assessed by the percentage of the signals missed on the secondary signal detection task. The assumption is that the greater the number of signals missed, the more demanding the driving situation. The main effect of both road type was statistically significant, F(3,39)=7.84, p<.0001. This effect can be seen in Figure 5. The figure shows that, regardless of the guidance method, given the same geometry, drivers miss significantly more signals when driving in the tunnel than on the open road. Furthermore, when driving in the tunnel, the POL guidance method and the absence of any cues appear to be less demanding than the equi-distant lines painted on the wall. However, this apparent difference was not statistically significant, F(3,41)=1.03, p=.39.



Figure 5. The effects of headway guidance method and road type on the percent of missed signals in the secondary signal detection task.

#### CONCLUSIONS AND RECOMMENDATIONS

The results of this study are quite conclusive and can be summarized as follows:

- 1. Driving in a tunnel is more attention-demanding than driving on the open road, and consequently more tiring. While driving in the tunnel drivers tend to have less spare capacity to respond to non-driving tasks than in the open road.
- 2. Maintaining headway with the POL may be less demanding than trying to maintain a fixed headway with equi-distant wall markings, but this still has to be tested further.
- 3. In the absence of supplementary cues to headway distance, it is very difficult to maintain long headways, such as the 150 meters required in the Frejus Tunnel.
- 4. Without any headway guidance methods, drivers under-estimate a long distance such as 150 meters. Therefore, when they actually attempt to produce the desired headway, the resulting headways are longer than the required distances. Also, without a guidance method, drivers are much more variable in their headways than with it.
- 5. Of the three guidance methods evaluated, the moving point-of-light is the best one as reflected by all three measures employed in this study:
  - a. Average headway with this method is closest to the desired one of 150 meters
  - b. The variability in the headway is less than with the other methods

c. The amount of attention (based on performance in the divided attention reaction time task) that the task requires is less than with the other methods, leaving the driver with more spare capacity to handle other driving and non-driving tasks

Based on these conclusions, it is recommended that the technological means to provide a moving point of light be pursued to the point where they are feasible and cost-effective. If the solution is too expensive, then repeated lines along the tunnel walls throughout the whole length of the tunnel can be used to help drivers maintain the desired headways, though with greater variability and at the cost of placing greater attentional demands on the drivers.

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