# Human-machine co-operation in car driving for safe lateral control in bends: function delegation and mutual control

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**Abstract**

This paper aims to identify in-car human-machine cooperation with automation for safety purposes through two experiments carried out on lateral control in bends. The first experiment tested a function delegation mode (FDM) where lateral control is fully automated and longitudinal control remains under driver control. This experiment demonstrated that there were serious difficulties in returning to manual control when skirting around an obstacle, although the device was easy to counter. In addition, spontaneous verbal reports indicated some difficulties in elaborating a mental model of the device and of the function allocation between the driver and the machine. There was also some negative interference between the driver's and the machine's driving styles. The second experiment dealt with the mutual control mode (MCM), where the entire driving task is fully controlled by the driver but the machine can evaluate lateral control and exert mutual control on the driver. It does this either by an auditory and haptic warning (steering wheel vibration) or by a haptic action suggestion (asymmetric oscillation on the steering wheel). The MCM experiment focussed mainly on the driver's recovery from critical situations (deviations provoked by visual occlusions). The warning mode was found to be efficient, whereas the results for the action suggestion mode were not conclusive, both for contextual reasons and because of larger individual differences. In addition, the mutual control mode appeared more efficient in the case of lane departure (toward another lane) than in the case of road departure (stress is much more efficient than mutual control).

## Introduction

While many studies have been devoted to driving support for longitudinal control (e.g., Adaptive Cruise Control, ACC), few studies have dealt with lateral control. A function delegation mode (Active Steering, ASt) has been compared to a kind of ACC on a simulator, as well as to a control situation without assistance (Stanton et al., 2001). A larger decrease in workload has been found with ASt than with ACC, although the former did result in difficulties in returning to manual control for collision avoidance. Indeed, this difficulty is considerable with ACC and with a

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combination of the two. Research has also been carried out on lateral control support with cooperation modes of a mutual control type, using auditory warning or action suggestion on the steering wheel (Suzuki & Jansson, 2003). However, there was no control condition in this experiment, which nevertheless concluded in favour of the auditory warning when the participants were not informed of the meaning of the stimulations. There was a variable effect of the action suggestion, with some participants misinterpreting the direction of the action to be performed.

There are two reasons why studies of human-automation cooperation of lateral control support in car driving may be as valuable as studies related to longitudinal support. First, depending on the type of indicator used (for example, global statistics, accident detailed analysis, fatality) and the country, road departure accidents make up a significant proportion of all road accidents (from 35% to 70%: Bar & Page, 2002). Second, studies of the automation of various driving functions are likely to provide researchers with more general results and more robust theoretical interpretations than studies that are too restricted to one kind of function and one type of device. For these reasons, two experiments on lateral control have been designed, taking advantage of the availability of equipped vehicles in a cooperating laboratory (LIVIC). Recent studies conducted at LIVIC (Netto et al., 2003) have resulted in the definition of three kinds of lateral control assistance aimed at maintaining the vehicle's position in the lane centre — a function delegation mode (FDM) and two mutual control modes (MCMs), namely a warning mode and an action suggestion mode. They operated on the basis of information obtained by frontal and lateral cameras which enable the vehicle to be located between lane markers. With the first mode (FDM), the lateral motion of the vehicle is delegated to the device; however, it can be deactivated at any moment by an easy counter action to the steering wheel applied by the driver. The two other modes (MCMs) are passive in the sense that no trajectory correction is applied to the vehicle and only haptic/sound alarms (mutual control) are activated when a dangerous situation is signalled.

The aim of the two experiments presented in this paper was to evaluate these different human-machine cooperation modes in lateral control, focussing on bend taking. They took place within the framework of a major French research program on driving automation for safety (Blosseville et al., 2003) — ARCOS — and of the European program PReVENT (SafeLane). The ARCOS philosophy was to consider the driver as the entity that has priority over the driving task. Thus, the goal was not to automate driving at any price, but to restrict the intervention of automation to that which is strictly necessary to avoid accidents, whilst also integrating a prediction capability. More precisely, these experiments took place within the theoretical framework delineated by Hoc and Blosseville (2003) in order to approach human-machine cooperation in car driving. The first experiment aimed at evaluating the function delegation mode with an automatic lateral control, leaving longitudinal control to the driver. This type of cooperation could be applied to very dangerous situations (e.g., a curve in a tunnel or mountain road). The evaluation did not concern the automated function, which is considered to be efficient, but rather the return to manual control in a situation where the device becomes invalid: for example, when there was an obstacle to skirt around in the centre of the lane in a bend. In this case, when driving in the lane centre, the device led the car towards the obstacle. Thus, the main problem was to characterise the difficulties in returning to manual control when the instruction was to skirt around the obstacle rather than to apply the brake, as was the case in an earlier experiment (Stanton et al., 2001). In contrast, the second experiment was designed in order to evaluate the two cooperation modes of a mutual control type — the warning mode and the action suggestion mode — in relation to a control situation without assistance (Suzuki & Jansson, 2003). The warning mode was implemented through a lateralised sound in the direction of the deviation and a non-specific oscillation on the steering wheel. The action suggestion mode was implemented through a lateralised oscillation on the steering wheel, prompting a response in the relevant direction without the steering wheel being turned. The aim of these evaluations was to increase our knowledge of human-machine cooperation. This includes any benefits derived and difficulties encountered, as well as ways of countering these difficulties whilst still being directed toward the best cooperation mode capable of resolving the application problem. Its originality lies in attempting to borrow a theoretical framework of human-machine cooperation, initially used at the level of symbolic information processing in aeronautics and process control, in order to model cooperation at subsymbolic levels (e.g., sensorimotor coordination): see, for example, Stanton and Marsden (1996).

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### *Co-operation activity levels*

According to Hoc (2001), cooperation implies several agents pursuing interfering goals and trying to manage this interference in order to facilitate their tasks. The definition of ‘interference’ used here is borrowed from Castelfranchi (1998) and assumes that one agent’s goal is relevant to that of another agent. More precisely, one agent’s goal can either facilitate the other agent’s goal (positive interference) or it can jeopardise the latter (negative interference). In the following experiments, we will see that the warning mode, for example, can facilitate the drivers in their task to return to the lane centre after a displacement (positive interference). On the other hand, the function delegation mode can also create problems during bend taking because of a difference between the device’s driving style (in the lane centre) and that of the driver (straightening the bends).

In terms of abstraction and anticipation, the cooperation activities, aimed at managing interference, can take place at three possible levels, both in terms of abstraction and anticipation.

*Action level*. Interference is managed locally and in the short term. Anticipation is minimal.
*Planning level*. Interference is managed at a less local level and in the medium term. At this level, the activities consist of generating or maintaining a common frame of reference between the agents. This framework is composed of representations (not

necessarily symbolic) of the environment and of the team's activity (e.g., function allocation between the agents).
*Meta-cooperation level*. As the agents gain experience of cooperating between themselves, they generate mental models of their operation mode and of their interactions (for ACC, see for example, Rajaonah et al., 2003).

*Co-operation modes*

Hoc and Blosseville (2003) proposed the categorisation of cooperation modes with automation into four classes relating to the assumed cooperation activities. Each cooperation mode can imply the three levels of cooperation activities; these must be considered as orthogonal to the cooperation modes. The classes range from the device that is most remote from action through to that which is the most active. However, this must not be confused with a dimension of increasing intrusion into the driver's activity.

*Perception Mode*. Nowadays, this is mainly restricted to the presentation of symbolic information, such as that displayed on the dashboard or on road signs. However, it may consist of reinforcing or augmenting the driver's perception in order to enter into the sensorimotor loops and to immediately trigger the expected response. If this mode is efficient, it is very intrusive because the strength of the relationships between perception and action can be very high. A typical example is the test of vision enhancement in fog or at night by infrared perception and a head-up display (Parkes et al., 1995).
*Mutual Control Mode*. Already presented above and studied in Experiment 2, this mode is aimed at criticising the driver's behaviour. We have chosen two modes, the warning mode being more remote from action than the action suggestion mode. There are two other modes which are closer to action, although these are not evaluated here — the limit mode offers resistance against the driver's action when the latter brings the vehicle out of the lane and the correction mode puts right any incorrect actions.
*Function Delegation Mode*. As mentioned above and studied in Experiment 1, the driver delegates part of the driving task to the device. The set point can be defined by the driver or by regulation (e.g., two-seconds headway in France for ACC). Among the difficulties usually encountered in human-machine cooperation, especially with the function delegation mode, we place particular emphasis on the complacency phenomenon (Moray, 2003; Parasuraman et al., 1993; Wiener, 1981). Under particular conditions (multi-task situations, high workload level, etc.), the delegation of a function to a machine can generate complacency with regard to the result produced by the machine; no attempt is made to improve it, whenever possible. Although the concept remains ill defined, there is a consensus on some of its main features — the information necessary to perform the function is neglected, as is supervision, and finally there is no correction. A minimal level of trust is usually considered as being necessary to the development of complacency, although the two concepts are different. The reasons for complacency can be very diverse and can also include the correlation between a decrease in workload and a decrease in attentional resources, as described by Young (2002).

*Fully Automatic Mode.* In this case, the overall driving task is automated, although the navigation task can remain under the driver's control.

*General hypotheses*

The function delegation mode was evaluated in Experiment 1. Taking into account the classical results of studies on human-machine cooperation, difficulties in returning to manual control were expected in situations where the device was invalid (obstacle skirting). These difficulties were in relation to complacency, leading to neglect of the visual information necessary to lateral control. Possible negative interference between the device's style and that of the driver in bends was also expected. Finally, a notable familiarisation effect could be expected in using the device.

The two mutual control modes were evaluated in Experiment 2. Here, the possible improvement in recovering from a critical situation (provoked by a visual occlusion) was at the core of interest. Mutual control at the time of the critical displacement was expected to reduce the time needed to return to the lane centre. The warning mode was expected to facilitate the diagnosis of the situation and the response preparation, and the action suggestion mode to facilitate the diagnosis and response triggering. However, the action suggestion mode could interfere with the driver's response. A previous simulator study (moving base) has shown that the warning mode was more efficient than the action suggestion mode when the drivers were not informed of their meaning (Suzuki & Jansson, 2003). The implementation of the action suggestion mode in this study led to very different results from one driver to another. Some of the participants were prompted to move in the correct direction, others in the wrong one. In the present experiment, if the auditory signal was lateralised, there was also a symmetric oscillation of the steering wheel (haptic modality) with the warning mode. Thus, there was no specific action suggestion on the effector, as was the case with asymmetric oscillation. The two implementations of the mutual control mode did not differ mainly in terms of perceptual modality — auditory versus haptic — but in terms of direct relations with a distinct activity module, namely diagnosis or response.

**Function Delegation (Experiment 1)**

*Procedure*

Two groups of 6 participants performed the experiment, first with no assistance (NA) followed by with assistance (WA) or the reverse order, thereby counterbalancing for order effects. All the participants (10 men and 2 women) had been driving on a regular basis for between 5 and 33 years.

The experiment took place on the GIAT test track in Satory (Versailles, France). The track is similar to a main road. Two opposite lanes were available. However, the participants drove in the left lane, without traffic, for safety reasons. The track included 14 bends (of diverse radii) and 15 straight sections along 3.4 km (Figure 1). The experimental vehicle (Renault Scenic) was equipped to enable the driver to delegate the lateral control function (automatically maintaining the vehicle in the lane centre and leaving the longitudinal control — in other words, speed control — to the driver) and to record some of the main vehicle parameters and the driver's actions (e.g., steering wheel angle and speed).

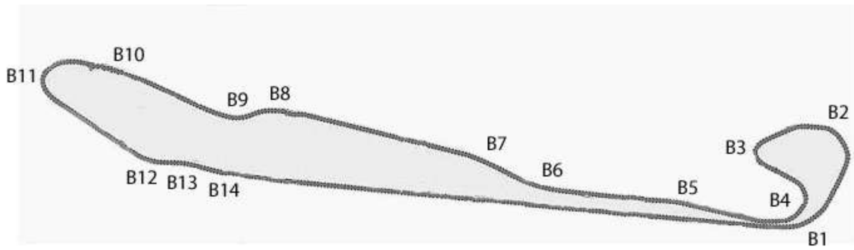


*Figure 1. The GIAT Satory test track. The participants were driving on the left-hand lane anticlockwise.*

After 2 laps to allow for familiarisation with the device, each participant drove 2 blocks of 2 experimental laps at free speed. Within each block, one lap was performed with no assistance and the other with assistance, in the order defined for the participant's group. Two bends (to the left) with short curvature radii (B1: 44 m and B11: 85 m) were selected for the sudden appearance of an obstacle (cardboard box). Each experimental lap included an obstacle to skirt around, but the participant could not anticipate what bend would be used. The allocation of obstacles to bends was counterbalanced so that a comparison between the two experimental conditions was possible for each bend.

In order to access symbolic information processing, spontaneous and concurrent verbal reports were recorded. A content analysis was performed, distributing the verbal report contents over the three main classes of cooperative activities — cooperation in action (interference during action execution), cooperation in planning (common frame of reference elaboration and maintenance), and meta-cooperation (elaboration of models of partners and of their interaction). An additional class related to complacency was introduced.

In order to indirectly access visual information processing, a recognition technique was used. For each participant, during the first lap driven without assistance and during the last lap with assistance, nine non-familiar advertising logos were placed close to one of two possible bends (different from those where obstacles were possible), counterbalanced. Three logos were placed in the straight-ahead visual field (visible when approaching the bend and in relation to the identification of the bend's visual angle and possibly in relation to speed adjustment). Three other logos were placed on the internal side of the lane (smaller than the former and in relation to visual processing of the tangent point (inside the bend, where the curve reverses) used for lateral control (Land & Lee, 1994). The last three were placed, like hoardings, off the road. Three distractors were also used. After the bend, the participant was invited to stop the car and to give a recognition judgement on each logo by means of drawing a cross on a 10 cm scale: 0 meaning that the participant is sure not to have seen the logo; 10 meaning that the participant is absolutely certain to have seen it.

As usual, in order to conclude on a population effect (δ) on the basis of an observed effect (*d*), a Student's *t*-test of significance was calculated. However, in order to draw conclusions in terms of population effect sizes (generalisation from judgements on the size of observed effects), a variant of Bayesian statistical inference (fiducial inference: Lecoutre & Poitevineau, 1992; Rouanet, 1996) was used. Below, fiducial conclusions on δ will be given with a .90 guarantee. For example, $\delta>0.26$ will mean "Prob($\delta>0.26$)=.90". When there is no interesting fiducial conclusion, we conclude that there is no generalisation from the observed effect to the population effect.

**Results**

Three variables were used in order to evaluate the quality of obstacle skirting. The first variable was the steering wheel angle amplitude, which was defined as the difference between the maximum angle during obstacle skirting and the angle at the beginning of the skirting manoeuvre. In this way, we were able to evaluate how smoothly an obstacle is skirted. The second variable was the time needed to skirt the obstacle, from the first response on the wheel through to the return to the lane centre when the obstacle has been overtaken. In this way, we were able to evaluate response anticipation. The third variable was the speed.

The observed steering wheel amplitudes are greater with assistance than without assistance in every case (NA→WA [$d$=1.28 rad.] or WA→NA [$d$=0.47 rad.] orders) and on average ($d$=0.88 rad.). This observation is easily generalised for the order WA→NA ($\delta>0.26$; $t(5)=3.26$ $p<.025$) and, to some extent, for the average ($\delta>0.22$; $t(10)=1.84$ $p<.095$: marginally significant). Thus, the response is less smooth with assistance than without assistance.

In every case, the duration of the manoeuvre is shorter with assistance than without assistance (NA→WA [$d$=1.50 s] or WA→NA [$d$=0.33 s] orders) and on average ($d$=0.92 s). This observation is easily generalised for the order NA→WA ($\delta>0.96$; $t(5)=4.11$ $p<.01$) and for the average ($\delta>0.40$; $t(10)=2.45$ $p<.035$). Below, we will see that the speed is slower with assistance than without assistance. Thus, if the time needed to skirt around an obstacle is shorter with assistance than without assistance, this fact reinforces the interpretation of a response that is less smooth with assistance than without assistance. The fact is also compatible with a more anticipated response without assistance than with assistance, in relation to lower steering amplitude.

Although it is not possible to generalise the result because of a lack of experimental precision, we observed an inversion of the recognition judgements from NA to WA. This was compatible with a negligence of information (tangent point) necessary to control the lateral dimension of the trajectory when this function is automated, with more importance given to information relevant to the longitudinal control (straight ahead). About 4% of the verbal reports are related to complacency (e.g., "Personally, I get used to doing nothing.").

For the bends used to set obstacles, when there was no obstacle, a comparison was made between the numbers of steering corrections with and without assistance. The device produced more corrections (4.0) than did the participants (2.3) ($d$=1.7; $\delta$>1.2; $t(10)$=4.70 $p$<.0008), probably because the device drove in the lane centre, whereas participants straightened up in the bends. Unfortunately, for technical reasons, it was not possible to get a reliable measure of the trajectory during this experiment. This difference in driving styles for taking bends created negative interference with the driver. About 19% of the verbal reports were related to this kind of negative interference (e.g., a feeling of knock on the hands when holding the steering wheel). It is not the case in straight sections, where interference was judged rather more positively.

On average, the speed is slower ($d$=6.6 Km/h) with assistance than without assistance, probably because the driver is not very confident in the function delegation mode. This result can be generalised ($\delta$>5.3; $t(10)$=7.22 $p$<.0001). However, with assistance, the speed increased between the first and the second lap ($d$=4.4; $\delta$>2.4; $t(10)$=2.95 $p$<.015). The verbal reports reflect this familiarisation process. 30% of reports relate to cooperation in action (interference). This reflects a vivid symbolic representation of the difficulties and facilitations which familiarisation is expected to reduce. 23% of reports are related to cooperation in planning (common frame of reference), particularly function allocation within the human-machine team (e.g., “I must take the control here.”). Finally, 21% reflect the elaboration of a model of the device (e.g., “It does not detect obstacles.”) and 19%, the interaction between the driver and the device (e.g., “In this bend, I am not sure that it will take it correctly and I am prepared to take over control.”).

More detailed results can be found in an earlier report (Jolly & Hoc, 2004).

**Discussion**

The delegation of lateral control to the device has clearly created difficulties in returning to manual control when the device is invalid; that is to say, when the car has to skirt around an obstacle in the centre of the lane. The pattern of higher steering wheel amplitude, shorter time needed and reduced speed led us to conclude that the response was later and less smooth with the delegation mode than without assistance. These difficulties can be due to diverse kinds of phenomena. Complacency is one of them, but the addition of two activity levels can also be an explanation. As a matter of fact, when confronted with this kind of situation, the driver must simultaneously: (a) decide to interrupt the function delegation, and (b) skirt around the obstacle. This can produce a late response. However, there is a link between complacency, which leads to the neglect of the delegated function, and the time needed for diagnosis and execution. Although the results cannot be generalised, the indirect information we have gathered from the recognition task is an argument for interpretation in terms of complacency. Within the function delegation mode there is some trace of negligence of the information necessary to perform the function (visual attention to the tangent point). Thus, this experiment confirms the border effects of function delegation. However, it encourages further studies to be carried out, aimed at finding solutions to these problems, as is the case with other domains such as aviation.

In addition to this main result, two complementary observations must be highlighted. First, there was clearly interference between the driver's and the device's bend-taking styles. This was expressed on the one hand by a sensation of uneasiness on the steering wheel. On the other hand, positive interference in straight lines was reported. However, the main problem to address is possibly when the driver learns a new calibration of the balance between speed and lateral acceleration. Furthermore, since we have observed that familiarisation effects still exist, the evaluation of this kind of cooperation mode should be developed over a longer period of time. At first, the participants slowed down with the delegation mode and then accelerated, at the same time developing complacency. In addition, verbal reports have been a way to identifying learning mechanisms concerning function delegation, the understanding of device operation and the management of human-machine interaction.

**Mutual Control (Experiment 2)**

*Procedure*

Twenty participants (mostly men, of various ages — from 24 to 50, 34 on average — and driving experiences — from 1 month to 34 years, 15 years on average) took part in Experiment 2.

Experiment 2 took place on the same test track as did Experiment 1. The experimental vehicle (Renault Scenic) was also equipped with measurement instruments to implement two mutual control modes — the warning and the action suggestion modes. In contrast to the function delegation mode previously described, these two devices are passive in the sense that no trajectory correction is applied to the steering wheel: as a consequence, the control of the vehicle motion (longitudinal as well as lateral) is under control of the driver. For both devices, the goal is to let the driver drive and, whenever a lane departure is signalled, the system gives an indication to the driver that something is going wrong. It is then up to the driver to carry out the task of correcting the trajectory. The fundamental difference between these two modes is the interference level with respect to the driver. In the warning mode (WR), symmetric square form oscillations are activated on the steering wheel, and a sound is emitted from the speaker situated on the side of the car's displacement. In the action suggestion mode (AS), dissymmetrical oscillations are generated in order to make the driver turn in the opposite direction to that of the displacement. The oscillations in this case are of a sawtooth form. The triggering of both devices is based on the magnitude of the lateral displacement (threshold equal to 60 cm).

Each participant performed 11 laps of the test track. The first lap was devoted to familiarisation with the track and the events that could occur. After that, for each implementation of the mutual control modes (warning and action suggestion), the participant performed 5 laps: 2 laps without assistance (NA) in order to constitute control conditions, 1 lap for familiarisation with the assistance (not analysed), and 2 experimental laps with assistance (WA). The participant received the instruction to drive in the lane centre at between 50 and 60 km/h. The presentation orders of the modes were counterbalanced, the presentation order being WR→AS for 10 participants and AS→WR for the others.

In order to test the modes, we created a critical situation where a deviation of 60 cm was provoked by a visual occlusion. Passing a sensor, the car triggered a visual occlusion (glasses with shutters) until it reached a 60-cm deviation.

Four bends with reasonable curvature radii were selected for incident allocation (Figure 1). Bend 6 (right; radius: 440 m) and Bend 7 (left; 231 m) were selected in order to test the warning mode (WR), and Bends 7 and 13 (right; 354 m) to test the action suggestion mode (AS). The allocation was defined in order to counterbalance the order effects and to enable comparisons to be made between the same bends, between control and experimental laps.

**Results**

The warning mode (WR) produced a decrease in the time taken to return to the lane centre after recovering vision. The reduction is large when the mode WR is the second to be presented ($d$=1.37 s for Bend 6; $d$=0.96 s for Bend 7). However, only the result for Bend 6 can be generalised ($\delta$>0.47 s; $t(6)=2.18$ $p<.07$: marginally significant). For Bend 6, the average effect (first and second position) can be generalised ($d$=0.83; $\delta$>0.40; $t(15)=2.57$ $p<.025$). No generalisation is reachable for Bend 7.

For the action suggestion mode (AS), although the observed result for Bend 7 is positive, no generalisation is reachable. The observed effect for Bend 13 is negligible ($d$=0.06 s on the average), but no generalisation is reachable. For Bend 7, the comparison between the individual effects of the modes has shown larger individual differences with AS than with WR. With a guarantee of .90, we can infer that the average standard deviation of individual average effects (between the two orders) is comprised between 1.43 s and 2.55 s for WR, whereas it is comprised between 2.77 s and 4.94 s for AS.

For each bend, we have tried to identify a possible behavioural change in the activity during occlusion from the non-assisted situation to the assisted one. In every case, the difference is negligible in terms of lateral and longitudinal control and the result can be generalised. More detailed results can be found in an earlier report (Hoc et al., 2004).

**Discussion**

The two mutual control modes were expected to have positive effects in critical situations where a decrease is predicted in the time needed to return to the lane centre after the displacement provoked by visual occlusion. Except for Bend 13, where the action suggestion mode had a negligible effect, the observed effects are always positive. However, only one effect can be generalised — the positive effect of the warning mode in Bend 6. This kind of result suggests being cautious in considering the bends as equivalent. There are some notable differences. The contextual situations at the end of the visual occlusion could partly explain the results (Figure 1). Bend 6 (to the right) was preceded by a straight line and followed by Bend 7 (to the left). An analysis of the lateral displacement during occlusion shows that, for Bend 6, the participants deviated to the right (toward the road centre). A typical straightening-up strategy when approaching Bend 7 (to the left) is compatible with this displacement toward the right when processing Bend 6. The warning mode was efficient. On the contrary, Bend 13 (to the right) was preceded by a bend to the left (Bend 12). The typical straightening up of a bend to the left leads to a displacement toward the left at the end of the bend, so that the driver enters Bend 13 near the left side of the lane, that is to say near the left side of the road. This is exactly what is shown by the analysis of the lateral displacement during occlusion in Bend 13. The stress provoked by the imminence of road departure in this case could have been sufficiently high to mask the effect of the assistance. In Bend 6, the situation was not a road departure, but a lane departure, which is less stressful, and the warning was efficient. In addition, it confirms the suspicions that, in terms of effects, the action suggestion mode can produce large individual differences.

**Conclusion**

The two experiments call for a continuation of these studies using a simulator in order to better control some contextual effects and to draw conclusions over longer periods of time. Taking into account these two aspects, the test track method reveals itself to be inadequate, despite having an appearance of ecological validity. In reality, technical and safety constraints largely influenced the choice of the bends where incidents were presented, of the driving lane (the left-hand one, although drivers were used to drive on the right), and of the absence of traffic. These constraints can be eliminated in a simulator. In addition, it will be easier and more affordable to study the long-term effects of the assistances with repeated driving tests in a laboratory setting. Such a project is now in progress.

Experiment 1 was not designed in order to test the efficiency of the function delegation mode with regard to trajectory safety in ordinary conditions where the assistance is valid. On the contrary, the aim was to identify possible difficulties when returning to manual control in situations for which the assistance was invalid. In particular, it was a way to checking whether a gain in safety on the one hand could result in a loss of safety on the other. Two types of negative effects were stressed — difficulty in returning to manual control and interference between driving styles. A complacency effect is suspected of being related to the negligence of visual information processing, calling for confirmation over longer periods of time. At the same time, the importance of its contribution to difficulties in returning to manual control should be evaluated. Other determinants of these difficulties should also be evaluated; for example, the addition of a strategic decision (control takeover and execution). If the effect is confirmed, a search for a countermeasure will be necessary; for example, by enhancing sensory cues involved in trajectory lateral control (such as the tangent point). The interference between driving styles in bends raises another kind of question. If a familiarisation effect with the assistance can be attained, then any interference could be eliminated with the possible integration of speed control. If this is not the case, the action of the assistance in bends should be adapted in such a way that the assistance's behaviour approaches that of the driver during bend taking (e.g., on the basis of similar visual information).

The study of mutual control modes (Experiment 2) demands further investigation. These modes were at times and in certain conditions, revealed to be efficient. However, more established generalisation is needed. Contextual conditions of critical situations and the interaction between stress and warning must be addressed. The large individual differences for the action suggestion mode should also be investigated. Finally, the efficiency of the assistances in terms of processing steps should be further examined. Although the addition of direct effects on diagnosis and response triggering could be efficient, a pure warning mode (e.g., sound) should be compared to a pure action suggestion mode. Later, the relevance of a limit or correction mode could be studied. For example, the warning and action suggestion modes could be useful as prevention tools and the two other modes as road or lane departure avoidance tools.

One should be cautious in adopting the function delegation mode for long periods of time on the sole basis of these two experiments. The warning mode looks like an efficient assistance, with a clearer effect than the action suggestion mode, but the comparison between the two modes was not conclusive. However, an important question remains concerning the types of situations where the different cooperation modes are expected to increase road safety. Is the function delegation mode relevant as a cooperation mode, with a sharing of driving functions between the assistance and the driver? In other words, does the delegation make sense outside the full automation perspective and is this perspective justified, at least within a certain class of situations that are difficult to manage by the driver? Are the mutual control modes relevant in critical (and stressful) situations or only upstream as the determinants of accidents (prevention strategy)? Finally, are these types of assistance more relevant to driving straight on than to bend taking? Further research should rely on precise accident reconstructions, although these are not very numerous and reliable.

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