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Understanding overtaking, beyond limitations of the visual system in making spatiotemporal estimations

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ABSTRACT

Motivation – To enrich our understanding of the factors that influence the decision to overtake against two way traffic, and this, beyond the limitations of the human visual system in making spatiotemporal estimations. Such understanding may be valuable for the design of future adaptive aid systems.

Research approach – An explorative naturalistic observation was conducted with a vehicle equipped with three cameras travelling at normal speed for a total distance of 300 km. 40 unobtrusive observations of overtaking episodes were recorded.

Findings/Design – The data is still at the analysis stage. There is however evidence that before the decision to overtake (i) there is a preparation phase prior to the initiation of the overtaking manoeuvre which deals with the intentions/state of the driver ahead and (ii) frequent users of the particular road will use their specific knowledge and initiate overtaking manoeuvres

Research limitations/Implications – The study has an explorative character mainly for generating hypotheses and cannot as such prove its findings without subsequent complementary methods.

Originality/Value – A contribution of the present paper is on the observation method which ensures the collection of data with a high degree of ecological validity.

Take away message – Spatiotemporal estimation just prior to manoeuvre initiation is only one of the factors influencing the decision to overtake. For understanding naturally occurring overtaking manoeuvres longer time frames of analysis are needed

Keywords

Driving, overtaking, naturalistic observation

INTRODUCTION

In this paper, a new approach for studying the overtaking manoeuvre is proposed based on naturalistic observation and phenomenological description. So far, the main research approach is based on a relatively limited number of laboratory and simulator studies, which concentrate on the accuracy of drivers' judgements as to whether it is safe to overtake against traffic or not. Results from these studies suggest that drivers, in general, are unable to estimate accurately the required distance gap for safe overtaking, namely, the distance gap between an oncoming vehicle and the vehicle being overtaken (Gordon & Mast, 1970; Jones & Heimstra, 1964; Bjorkman, 1963). More recently, Gray & Regan (2000; 2005) suggested that drivers not only make inaccurate distance estimations, but also make inaccurate temporal estimations of the projected moving distances of the other road users.

Also, from a cognitive point of view, Hills (1980) formulated the hypothesis that a driver's perceptual judgement, whether it is safe to overtake against traffic or not, is highly affected by his ability to estimate concurrently the future spatial-temporal position of at least three road users: the upcoming vehicle, the vehicle ahead, and the ego-vehicle (i.e. the overtaking vehicle). Given the high cognitive demand on the overtaking driver, some authors have claimed that unless there are serious reasons for monitoring the driving behaviour of the vehicle ahead (e.g. a sudden deceleration, a "hissing" sound from the air brakes of a heavy goods vehicle, etc.) the overtaking driver deals only with the upcoming vehicle rather than the vehicle ahead, as if the latter were stationary, in an attempt to simplify the complexity of the situation (Clarke, Ward & Jones, 1999). Moreover, interviews with drivers who had been involved in head-on collisions revealed that "they picture the manoeuvre as putting them slightly ahead of the overtaken vehicle's initial position". Thus as the authors note "they seem to imagine the overtaking of a moving vehicle, in terms of the time and distance needed to overtake a stationary one" (Clarke, Ward & Jones, 1998, 465).

Due to the above mentioned visual /perceptual and attentional limitations of the overtaking driver's judgement, it is questionable whether a driver's decision to overtake rests solely on perceptual estimations about the future spatio-temporal position of the other road users. A research question that arises, then, is what other cues may drivers rely on, to overcome these limitations?

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A PHENOMENOLOGICAL DESCRIPTION OF OVERTAKING

Some insight to the above question, are offered by the findings of a naturalistic observation of 442 overtaking manoeuvres on a two-lane British "A" carriageway (Wilson & Best, 1982). In this study, a number of overtaking strategies were identified (i.e. *flying overtakers, accelerative overtakers, piggybackers, braking-to-follow overtakers).* Each one had different impact in terms of lane-sharing and cut-in (i.e. returning to initial lane), and this was strongly related to the preconditions before overtaking, namely, the speed of the overtaking vehicle and its distance from the vehicle ahead.

More recently, Hegeman et al. (2005) used an instrumented vehicle equipped with a camera to observe overtaking manoeuvres performed by unsuspecting drivers, in two lane rural roads in the Netherlands. In agreement with the above mentioned findings, they identified four overtaking strategies (i.e. *normal, flying, piggy backing, 2+*), three of which were identical to those described by Wilson and Best (1982). They also performed a task analysis of the overtaking manoeuvre and divided it into five phases: (i) deciding whether to overtake or not, (ii) preparing to overtake, (iii) changing lane, (iv) passing and (v) returning to own lane. Using the video observations, the task analysis revealed that the two main sources of error in the judgement of the spatio-temporal availability for an overtaking manoeuvre are related to the driver's observation and/or estimation limitations, that correspond to the phases (i) and (ii), respectively (Hegeman, 2009).

However, such an argument becomes circular. Results from laboratory and simulator studies show that drivers' estimations are generally inaccurate. An open issue then remains: should the observed behaviour (e.g. lane sharing, cut-in) be considered solely as a side-effect of a driver's initial erroneous estimation or also as a strategy that drivers "deliberately" adopt due to their perceptual limitations? If one subscribes to the second hypothesis, it is rather reasonable to assume that drivers may deliberately search for further relevant cues. Adopting the phenomenological approach, in the present study we are interested in examining in more detail the whole "episode" of overtaking against oncoming traffic, as it occurs in a naturalistic setting. To this end, a working model for describing overtaking has been developed.

The main assumption in our model is that overtaking evolves within two discrete time frames. In the short timeframe we place the drivers' perceptual judgement for overtaking initiation, more or less in the way it has been described by previous research. A difference is that we consider this perceptual judgement to be evolving dynamically. This is needed since we identify intermediary decision points during the manoeuvre.

In the longer time frame, we place the driver's overall situation assessment and adopted strategy. Situation assessment and strategy are based on a number of factors, other than spatio-temporal ones (e.g. knowledge of specificities of particular road segments by frequent users of the road, time constraints for travel, motivational factors, etc.). All the above may variously influence a driver's decision to overtake the vehicle ahead. However, apart from these factors that may play a role in the overall assessement, there is also a sort of "acquaintance" with the driver of the vehicle ahead and/or the driver of the oncomming vehicle. Specifically, before initiating an overtaking, a driver may deliberately try to communicate his/her intention to the driver of the vehicle ahead, by using signals (i.e. indicator sign, headlights) as well as by preparing and placing appropriately his/her vehicle on the road (i.e. changing gear, placing his/her vehicle near the central axis). The interlacement of these actions permit the overtaking driver, on the one hand, to monitor the oncoming road/traffic conditions, and on the other hand, to get feedback about the state (e.g. alertness) or possible intention of the driver ahead (e.g. moving towards the auxiliary lane or not).

Depending on the latter, the driver evaluates the possibilities for overtaking and may initiate an overtaking manoeuvre by performing the perceptual judgment for overtaking (as in the short time frame). In addition to his decision to overtake, the above evaluation will also determine his overtaking strategy. For example, in case of a straight segment of road with no-oncoming traffic, flying or accelarative overtaking with a large lateral displacement is a viable strategy. If one adds to this an oncoming vehicle, flying or accelarative overtaking might be rejected or might as well be tried by means of lane-sharing. However, lane sharing presupposes an additional sort of "acquaintance" with the driver of the oncoming vehicle ahead, suggesting to the overtaking driver the possible intentions of the other (oncoming vehicle) driver. Thus, depending on the "mute" dialogue between the overtaking driver with the driver of the vehicle ahead, it is possible for the overtaking driver to return to his own lane either leaving a small gap in front of the vehicle being overtaken (cut-in) or at a larger gap, if it is judged as safer to continue.

Therefore, in our working model we assume that i) the driver's decision to initiate an overtaking manoeuvre is neither solely based on perceptual estimation; nor that such an estimation is taking place only once, and ii) the driver's overtaking strategy depends, among other factors, on a "mute" dialogue with the driver of the vehicle ahead and subsequently with the driver of the oncoming vehicle. The present research is still in an explorative phase. In an attempt to clarify the above issues, we present our preliminary results regarding the identification of possible artefacts /strategies that overtaking drivers use to execute their overtaking manoeuvres.

METHOD

To ensure the ecological validity of our naturalistic observations, the following method was used. The observation was conducted at the intersecting arterial highway connecting the cities of Korinthos and Patra, Greece (a round trip of 300km). The selected highway has a high traffic volume, and is characterised by frequent incidents of overtakings. A particularity of this highway is that it is used as a two-lane two-way road, although it actually has only one main-lane (3m wide) plus an auxiliary lane (1,5m wide) per direction. The highway has no safety barrier. It is marked with road delineation at the central axis and a solid edge line between main lane and auxiliary.

The vehicle used for this study (V_e) was equipped with three cameras (one camera was mounted on the dashboard, recording the visual scene of the road ahead, and two cameras were mounted on the shelf of the rear window, recording the rear visual scene). The driver of V_e was asked to drive normally at a constant speed (5km/h below the speed limit) and to maintain a steady lane position (with the right front-wheel near to the edge-line of the main lane). Due to the characteristics of the arterial, the driver of a following vehicle, in order to overtake, should necessarily move into the lane used by the opposing traffic and return into the initial lane after overtaking. Thus, the objective of our observation was to record, simultaneously (i) the manoeuvre of the overtaking vehicle (V_o), from the moment it appeared on the rear visual scene until the moment it returned to right lane in front of V_e. and (ii) the road/traffic conditions (i.e. oncoming traffic vs. no-oncoming traffic, straight road vs. curved road, etc) during the overtaking "episode". At the end of this procedure the data of the three cameras were synchronized and cut into overtaking episodes.

ANALYSIS

A total of 45 overtaking "episodes" were analysed. Initially, a time-line diagram of all overtaking episodes was created, in an attempt to identify all the observable events that took place during each episode.

From the above, a set of parameters related to the movement of V_o was defined, namely:

i. *time of initial lateral displacement* of the V_o before overtaking initiation,

ii. *inter-vehicle distance between V_o and V_e* – (D1) at the moment of overtaking initiation,

iii. *relative velocity of V_o* during overtaking manoeuvring,

iv. *overtaking manoeuvring duration,* and

v. *inter-vehicle distance between V_o and V_e* – (D2) at the moment that V_o returns into the initial lane.

In addition, another set of parameters related to the road/traffic conditions was defined, namely:

vi. the *available time margin with road visibility*,

vii. the *available time margin for meeting the next oncoming vehicle,*

at two points in time:, when the V_o initiates overtaking and when the V_o exceeds the V_e.

All the above parameters were estimated solely on the basis of optical measurements, using appropriate image software for processing video data. Although the estimation accuracy is non-optimum the data calculated is of value for testing whether or not certain tendencies or patterns exist.

At a first place, we considered the total number of overtaking episodes (N=45) and examined whether there is a correlation among the road/traffic conditions and the set of parameters related to the movement of V_o. The data were analysed using product moment correlation coeficient and an alpha level of .05. Results showed that there was a correlation between the available time margin for meeting the next oncoming vehicle, before overtaking initiation, with overtaking manoeuvering duration ($r=0,3196$, $p<0,05$), as well as, with the inter-vehicle distance between V_o and V_e at D2 ($r=0,3906$, $p<0,01$). No other correlation was found.

Accordingly, we considered two particular aspects of the overtaking drivers' behaviour, namely:

i. *the communicating signals* that the driver of Vo might used (i.e. indicator sign, headlights) before overtaking initiation, and

ii. *the overtaking strategy* that the driver of Vo adopted, following the classification described by Wilson and Beast (1982).

In total, three overtaking strategies were found: *flying (N=12), accelerative (N=28), and piggybacking (N=5).* A cluster analysis was used to examine the relation among the three overtaking strategies and the set of parameters related to the movement of V_o, as well as the communicated signals. From this analysis it was found that each strategy is related with a distinct behavioural pattern in terms of overtaking preparation, initiation and termination.

More specifically, in flying overtaking the mean preparation time before overtaking initiation (mean=2.55s., sd=2,3) was smaller than piggybacking (mean=3.66s., sd=2,5) and much smaller than accelerative overtaking (mean=8.48s., sd=7,6). On the other hand, 9 out of 12 (75%) of flying overtakers and 5 out of 5 (100%) of piggybackers used a communicating signal before initiating the overtaking manoeuvre in contrast to 13 out of 28 (46%) of accelerative overtakers. That is to say, the smaller the time of preparation before overtaking initiation, the larger the need of overtakers to acknowledge their intention to the driver of V_e.

Thus, in flying overtaking the mean inter-vehicle distance (D1) at the moment of initiating the overtaking (mean=14.27m, sd=2,9) was larger than piggybacking (mean=10.52m, sd=4,3) and even larger than accelerative overtaking (mean=7,48m, sd=3,6).

Finally, in flying overtaking the mean inter-vehicle distance (D2) at the moment that V_o returns into the initial lane was larger (mean=10.77m, sd=4,4) than piggybacking (mean=8.81m, sd=4,7) and even larger than accelerative overtaking (mean=7,34m, sd=3,1). What this shows is that the larger the initial inter-vehicle distance (D1) before initiating overtaking the larger the inter-vehicle distance (D2) at the moment that V_o returns into the initial lane.

The above findings might sound self-evident or simply consistent with the overtaking strategies used. However, adopting a particular overtaking strategy is not prescriptive of the way that drivers overtake.

In particular, in 11 out of 28 accelerative overtakings it was observed that overtaking manoeuvre was performed by means of lane sharing without cut-in, because the driver of the oncoming vehicle performed a lateral displacement. The same was also observed in 6 out of 12 flying overtakings and 3 out of 5 piggybackings. This suggests that in 20 out of 45 overtakings there was a kind of "dialogue" between the overtaking driver and the driver of the oncoming vehicle, during the overtaking manoeuvre. However, our video data do not permit us to identify the type of communication involved (e.g. explicit signals, progressive adjustment).

DISCUSSION

The motivation for the present study came from the observation that most current models of automobile overtaking, although accurate from a purely perceptual point of view, cannot account for the full complexity of driving as it occurs in natural settings. This limited scope becomes a hindrance not only for the task of understanding naturally occurring overtaking per-se but also for the practical aim of specifying the driving aids of the future. Specifically the implicit interaction between drivers, the explicit signs and / or nuances can provide a better understanding of the ecology of the road, the real risks involved and the drivers' more or less deliberate risk management strategies. Future systems need to take into account i) what is perceived as acceptable risk and ii) what corrective / collaborative adjustments might occur during an overtaking manoeuvre. A purely technocratic approach at improving traffic safety would reject the above subject of study right from the start. On technical grounds tomorrow's aids for overtaking need only be based on the physics of the operation. But also, on legal grounds such overtaking behaviours are categorized as either non compliant (in a regulatory sense) or even as aberrant. However such techno/regulatory views hinder the pragmatics, i.e. that drivers actively negotiate, collaborate and/or fight against each other for a balance over a shared resource namely the level of acceptable safety. Overtaking is a privileged area for such an endeavour.

To this end, a working model for describing overtaking has been developed. Two main assumptions of this model are: (i) there is a preparation phase prior to the initiation of the overtaking manoeuvre which deals with the intentions/state of the driver ahead i.e. the driver's overtaking strategy depends, among other factors, on a "mute" dialogue with the driver of the vehicle ahead and subsequently with the driver of the oncoming vehicle and (ii) frequent users of the particular road will use their specific knowledge and initiate overtaking manoeuvres. Our observation data so far support the model claims but further work needs to be done both in terms of developing the model and on measurement techniques. Thus, the study has an explorative character mainly for generating hypotheses and cannot as such prove its findings without subsequent complementary methods.

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Design concepts and solutions