STEERING ENTROPY AS A MEASURE OF IMPAIRMENT

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The driving task requires sustained physical effort and concentration, which could be easily disturbed by either a secondary task or impairment. The steering entropy modelling technique has previously been used to measure workload imposed on the driver by a secondary task. This study investigates whether this technique would be suitable to detect driver impairment, which similarly to a secondary task, can cause inattention to the primary driving task.

INTRODUCTION

The task of driving generally requires continuous effort and concentration, which could be easily disturbed. Driver impairment is one element that could have a detrimental effect on driver performance. The purpose of this study was to investigate whether entropy modelling techniques can be used to observe dscontinuities in smooth patterns of movement and if so whether these can discriminate between impaired and non-impaired and even between different levels of impairment.

The field of in-vehicle systems is a fast moving industry, with evermore complex systems emerging. The general public and government have started to question whether the use of these in-vehicle systems whilst driving is safe. There is a need to easily and accurately assess the extra workload placed on drivers by operating such systems. Simple and easy to use evaluation tools are required because of the fast pace of technological advances and the development of new products at short time periods. Assuming that the driver's workload or driver impairment will be measured each time a new device is developed, the measurement procedure must be simple and easy to apply. The entropy model has the potential to be the solution. This section very much builds on the work carried out previously by Nakayama et al (1999) and Boer (2000). However, their work adopted the steering entropy model for workload measurements, while this study concentrates on measurements of impairment.

Theory of steering entropy

While driving a vehicle, drivers continuously assess the situation ahead and unconsciously employ smooth and predictable steering control. Smooth in this instance can be defined as turning the steering wheel a little at a time in small increments. When drivers are distracted (or impaired), the driver does not monitor the environment effectively and the vehicle deviates laterally. As an example, Figure 1 shows steering data over a period of 1.5 km before and after the consumption of an alcoholic drink. It can been seen that the alcoholic drink resulted in the driver performing more large amplitude steering manoeuvres. The steering entropy method is connected to these corrective steering manoeuvres.

Steering predictability decreases as drivers introduce more error corrective manoeuvres. Drivers introduce more error corrective manoeuvres as distraction (due to a secondary task or impairment) increases.

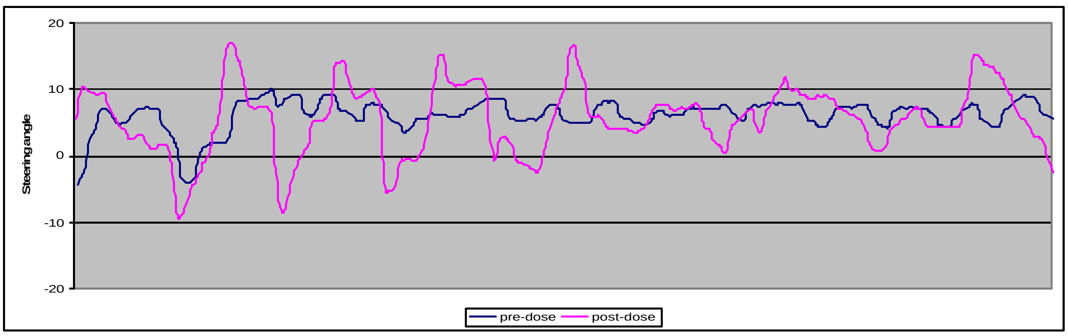

Figure 1: Pre and post dose steering data

PRE-TRIAL STEERING ENTROPY STUDY

Prior to the main trial, one participant was asked to drive the simulator in a normal manner, a purposely extremely erratic manner, and whilst using a personal digital assistant (PDA), which is an extremely loading secondary task. The aim was to obtain steering angle data to enable initial calculations to be made of steering entropy and to investigate whether this method of measuring predictability (inattention) would be successful.

The steering angle was recorded every 15 milliseconds. This data was averaged over 150 millisecond periods, as this was indicated to be a good sampling interval in previous research. It also corresponds to the lowest sampling frequency that can be used to represent a human operator's control response in manual tracking tasks (Nakayama et al. 1999).

Having obtained this data, a second-order Taylor expansion on time was performed to make a prediction of the steering angle at a given time. This was done by using three preceding data points using the following formula:

$$q_{p(n)} = q_{(n-1)} + \left(q_{(n-1)} - q_{(n-2)}\right) + \frac{1}{2}\left(\left(q_{(n-1)} - q_{(n-2)}\right) - \left(q_{(n-2)} - q_{(n-3)}\right)\right) \text{ which simplifies to;}$$

$$q_{p(n)} = \frac{5}{2}q_{(n-1)} - 2q_{(n-2)} + \frac{1}{2}q_{(n-3)}$$

The difference between θ(n) (actual) and θp(n) (predicted) is defined as the prediction error e(n) as illustrated in Figure 2.

$$e_{(n)} = q_{p(n)} - q_{(n)}$$

A prediction error was calculated every 150 ms and this data was examined to make sure it was normally distributed.

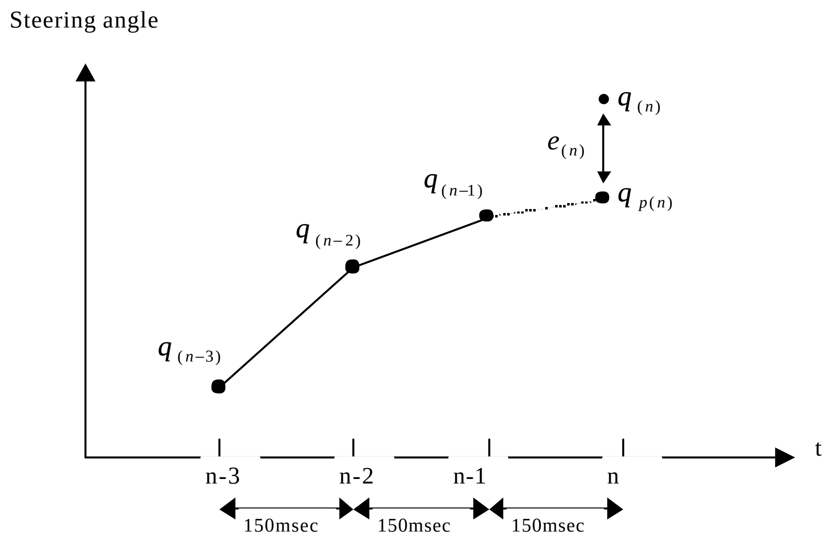

Figure 2: Steering angle prediction (Nakayama et al. 1999).

The mean prediction error was calculated using 1.2 standard deviations, which encompasses 90 percent of the data. 90 percent of the data falls between -α and α. The smaller the value of α, the smoother the driver's steering behaviour. Initial results of α were promising as illustrated in the table below:

Driving condition	a
Normal	1.52
Severe erratic	10.65
Demanding secondary task	7.64

The prediction error distribution was then divided into 9 bins based on α for normal driving. The steering entropy value Hp was calculated using the following formula (Nakayama *et al.* 1999):

$$Hp = \sum_{i=1}^{9} - p_i Log_9 p_i \quad \text{where } p_i \text{ is the probability of being in bin } i$$

The results of steering entropy were as follows:

Driving condition	**Hp**
Normal	0.46
Severe erratic	0.95
Demanding secondary task	0.81

This is illustrated in Figure 3.

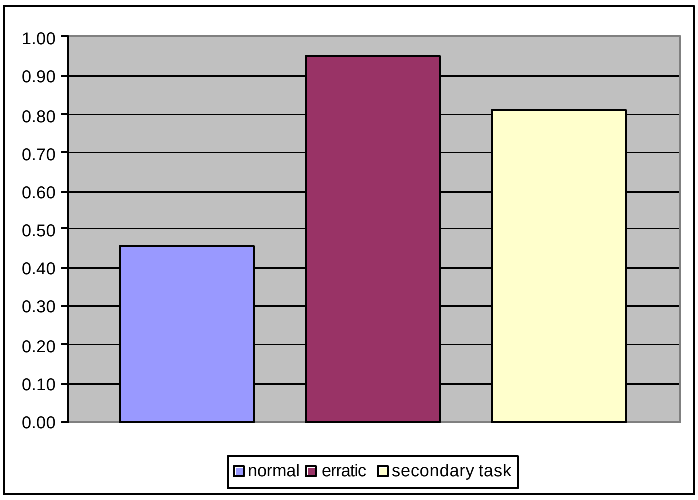

Figure 3: Steering entropy for normal driving, erratic driving and driving whilst carrying out a secondary task.

Steering entropy has previously been used as a measure of workload, investigating how much workload increases when performing a secondary task whilst driving. When performing a secondary task, driving becomes less smooth and attention to the driving task decreases. When drivers are impaired, attention to the driving task reduces in a similar way. In this pre-trial experiment, driving in a purposely erratic manner was used to simulate impairment. This impairment manifests itself in a decrease of attention to the driving task and less smooth driving. This pre-trial showed that the method used seemed successful and enough confidence was gained to carry on with the main trial described in this report.

STUDY METHOD

Six participants were invited to attend a trial session, three female and three male. The participants attended in the morning after a normal night's sleep and a light breakfast. They were asked to drive the simulator, carry out a Critical Flicker Fusion (CFF) test, Choice Reaction Time (CRT) task and Adaptive Tracking (AT) task. They also filled in a Participant Self-Evaluation Form and a Breath Alcohol Concentration (BAC) reading was taken. All this data was taken as a baseline for comparison purposes.

The route participants were asked to drive was a 20 km long empty motorway. The first 6 km consisted of a more or less straight motorway followed by long right and left curves with a constantly changing curvature.

After the baseline data was collected, participants were asked to consume an alcoholic drink, which contained a measured amount of alcohol - based on the participants height and weight - mixed with the same amount of a soft drink (coke, soda or lemonade). The amount of alcohol given to participants aimed to reach the legal limit of BAC (80mg/100ml). Participants were asked to consume the drink within 20 minutes.

Forty-five minutes after starting the consumption of the drink, participants were asked to drive the simulator again (using exactly the same route), carry out a CFF, CRT, AT and fill in a self-evaluation form. BAC readings were taken every 15 minutes. The CFF, CRT and AT were repeated for a further three times at approximately 30 minute intervals.

DATA ANALYSIS

The data from the BAC, CFF, CRT, ATT and self-evaluation forms were entered onto a spreadsheet. Due to the small number of participants, it was not possible to carry out statistical tests. The steering angle data was automatically derived from the driving simulator.

Breath Alcohol Concentration (BAC)
Figure 4 illustrates the BAC readings taken during the trial, the first one being 30 minutes after the consumption of the alcohol. As expected, it shows that male participants absorbed alcohol quicker than female participants.

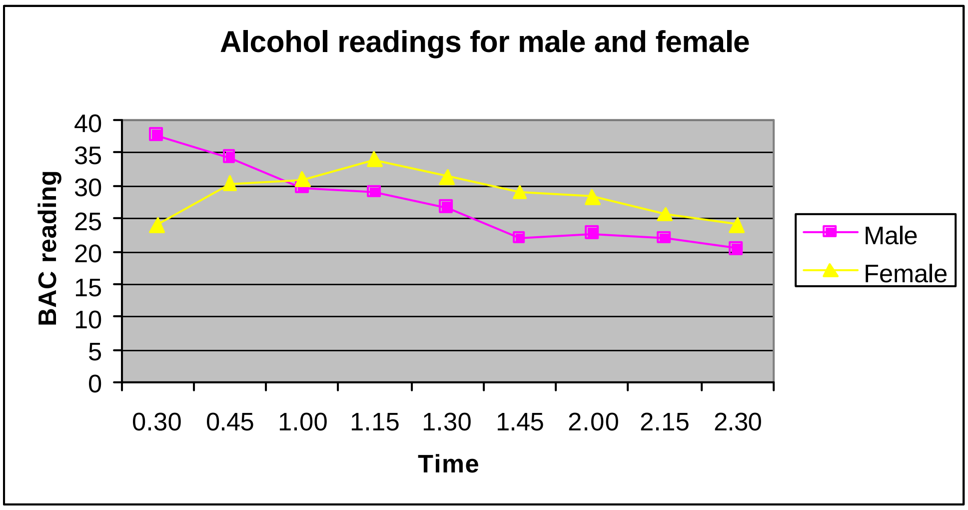

Figure 4: BAC readings for male and female

Critical Flicker Fusion
The average scores of the Critical Flicker Fusion were between 31.68 and 32.54. A higher score represents better visual performance. No recognisable pattern of deterioration was shown.

Choice Reaction Time
The Mean Total Reaction Time (M-TRT) failed to demonstrate any effects on CRT scores related to impairment. The Mean Response Reaction Time (M-RRT), however shows encouraging results as illustrated in Figure 5. Prior to the drink, participants' performance was superior over the other conditions in which the drink had been consumed. This means that participants took more time to detect the illuminated light when impaired. The more alcohol was absorbed, the longer the perceptual processing took and when the alcohol level decreased so did the response time.

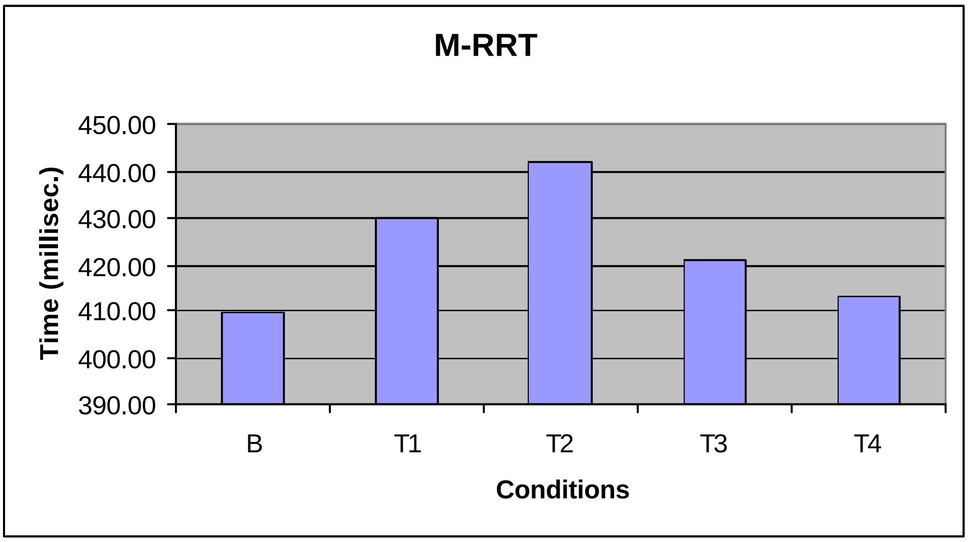

Figure 5: Mean Response Reaction Time per condition

Adaptive Tracking
The results of the adaptive tracking task showed no recognisable pattern.

Steering entropy
Every 15 milliseconds steering angle data was recorded for the whole 20 km drive. This data was averaged into one data point per 150ms. The prediction error was calculated and checked for normal distribution. Figure 6 illustrated the distribution data of one participant. The post-dose data shows a broader distribution with a lower peak and thus more unpredictable steering took place whilst participants were impaired.

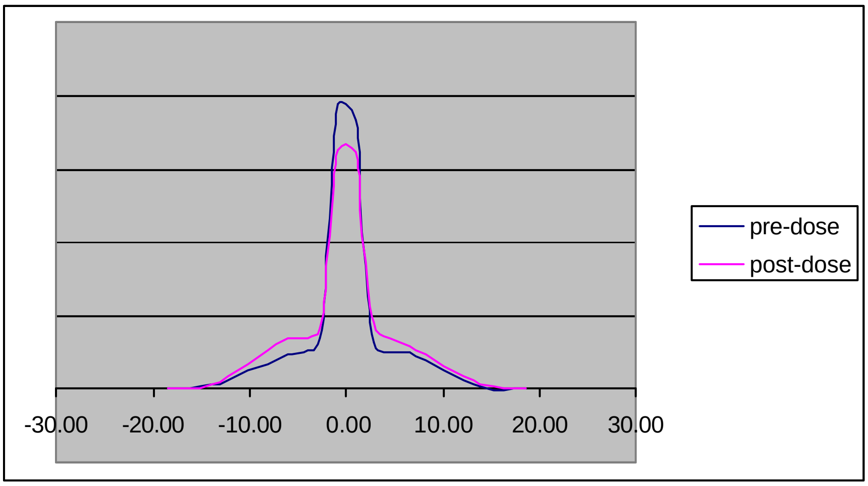

Figure 6: Distribution of pre and post dose prediction error data of one participant
All data overall was examined, as well only data related to 1 km of straight road, 1 km of left curved road and 1 km of right curved road.

Calculations of α took place per participant per type of road. An example of the results is given in Table 1, which shows that the post-dose α values are higher than pre-dose. This was to be expected, as a narrower prediction error distribution would have a smaller value of α representing normal driving where steering predictability is relatively great.

Table 1: Pre dose and post dose a for 1 km of straight road.

Subject	pre-dose a	post-dose a
01	1.81	1.93
02	1.04	1.28
03	1.34	1.79
04	1.23	2.58
05	1.56	2.27
06	1.46	1.70
Average	**1.41**	**1.93**

The prediction error distribution was divided into 9 bins based on α per participant for normal driving. The proportion of prediction errors falling into each bin was computed and the steering entropy (Hp) was calculated. Table 2 shows the steering entropy values per subject as well as an average over all subjects, while Figure 7 shows a graphical representation of the average steering entropy values over all six subjects per road type.

Table 2: Pre and post dose steering entropy (Hp) per subject

Subject	Overall (20 km)		Straight (1km)		Left curve (1km)		Right curve (1km)	
	Pre-Hp	post-Hp	Pre-Hp	post-Hp	pre-Hp	post-Hp	pre-Hp	post-Hp
01	0.43	0.48	0.46	0.45	0.43	0.61	0.50	0.56
02	0.44	0.46	0.50	0.51	0.52	0.53	0.51	0.60
03	0.43	0.55	0.38	0.56	0.48	0.69	0.51	0.80
04	0.41	0.51	0.41	0.69	0.45	0.53	0.52	0.51
05	0.42	0.35	0.47	0.60	0.44	0.29	0.53	0.40
06	0.43	0.42	0.48	0.40	0.50	0.46	0.49	0.61
Average	**0.43**	**0.46**	**0.45**	**0.54**	**0.47**	**0.52**	**0.51**	**0.58**

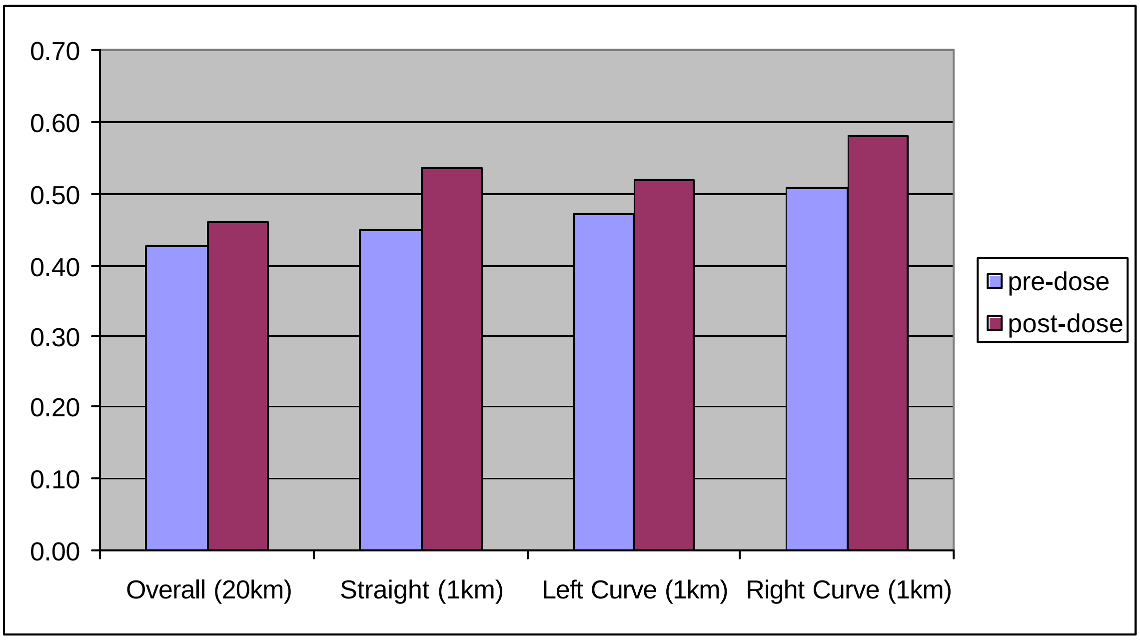

Figure 7: Average steering entropy values over all six subjects per type of road.

The differences between the values of pre and post dose steering entropy are as follows:

Overall	0.03
Straight	0.09
Left curve	0.05
Right curve	0.07

These differences seem small in itself, but when compared with previous research carried out (Nakayama et al. 1999) they are similar to carrying out the following tasks:

0.03 Checking a navigation system; checking the map position and the name of the location shown on the navigation system screen.
0.05 Mental arithmetic; counting down as fast as possible starting from a number around 950 by subtracting 7 each time
0.10 Selecting a name from a list; looking at a list of four names displayed on a navigation system screen and choosing the preferred one.

The post steering entropy values for participants 5 and 6 are not consistently higher than the pre steering entropy values. This does, however correspond with their subjective self-evaluation forms in which they indicated that they felt extremely tired before commencing the trial. Differences between pre and post dose excluding participant 5 and 6 are slightly higher ranging from 0.07 to 0.12.

Self Evaluation
The self-evaluation form analysis showed that participants felt more unwell whilst driving than when not driving. Participants also felt more unwell after they consumed alcohol. It should be noted, however, that none of the values, on average, scored above 1 with 0 meaning no symptoms and 6 meaning extreme symptoms.

DISCUSSION

The pre-trial steering entropy study showed promising results, as the Hp value for erratic driving and driving with a secondary task were considerably higher than in the normal driving condition. Enough confidence was gained to carry out the main trial.

The results of the breath alcohol concentration scores indicated that the treatment manipulation was successful for male participants. Female participants reached a breath alcohol concentration of just below the legal limit. The alcohol dose used for female participants will be slightly adjusted in future alcohol related trials to reach the legal BAC limit.

This manipulation was not reflected in detectable impairment or deterioration in performance in the critical flicker fusion test, overall score of the choice reaction time task and the adaptive tracking task, which is disappointing. However, it is encouraging that the mean and best mean response reaction time of the CRT task, as well as the steering entropy model seem to detect lower level impairment and deterioration in performance.

The average CFF scores were between 31.68 and 32.54 and did not show a recognisable pattern of deterioration in performance. This test therefore, does not seem suitable for detection of low level impairment.

The M-RRT data of the choice reaction time task showed that participant's processing speed decreased when impaired. The alcohol seemed to have most effect when participants conducted the CRT-task for the second time after the consumption of alcohol, approximately 1.15 hours after they started consuming the drink. The reason why the RRT data does show results, while the TRT data failed to do so, is likely to be due to over enthusiasm of participants. Participant's response time to the detection of the target, as their finger leaves the starting position, is the same in the RRT data and TRT data. Participants might have failed to cover the target, or after having covered it, might have failed to cover the starting position initially. These errors are incorporated in the TRT data, while they are eliminated in the RRT data. The errors have a large influence on the average TRT score, making the data more variable and therefore failing to show the influence of impairment.

Average steering entropy data showed higher values on all road types in the post-dose condition. Individual steering entropy values for participants 5 and 6, however, did not show such ideal results. The self-evaluation forms in which they indicated to be extremely tired before commencing the trial could explain this. The steering entropy values could be influenced by route familiarity, as the carried out pre and post routes have to be exactly the same.

CONCLUSION

The purpose of this trial was to investigate the ability of the steering entropy method to detect low levels of impairment caused by alcohol.

It would appear from the breath alcohol concentration that female participants did not quite reach the level of alcohol intoxication intended. As 50 per cent of the participants were female, this no doubt had an impact on the test results, although some promising results have been reached.

Impairment tests such as the adaptive tracking task, critical flicker fusion and self-evaluation forms did not show significant differences in performance before and after the consumption of alcohol. This could be due to the low level of impairment as well as the low number of participants.

The steering entropy method showed promising results. The fact that participants are unaware that measurements are taken, bias is excluded and low-level impairment seemed to be detected shows that this method has strong potential for impairment testing. A larger, more comprehensive trial would be needed to validate this method reliably.

The method itself could also be developed in terms of parameters used and application to real-time processing, such as in a real vehicle during normal driving.

A key question for the potential application of this method in the future is if, and how, it could be integrated into actual vehicles.

If the method was validated and developed to be able to determine a baseline for a given driver's behaviour, based on previous drives or small sections of a 'current' drive then basic sensors could be attached to the steering input control in the vehicle at very low cost. A small microprocessor could then process the signal and calculate the steering entropy, electronically 'flagging' continued behaviour suggestive of impairment, possibly ultimately leading to an intelligent vehicle that could alert or warn an impaired driver. If the driver failed to respond to the warning, it could then be possible to change the performance characteristics of the vehicle, for example gradually reducing the effect of the accelerator.

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