Digital and video analysis of eye-glance movements during naturalistic driving from the ADSEAT and TeleFOT field operational trials - results and challenges

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ABSTRACT
The EU projects ADSEAT (2009-2013) and TeleFOT (2008-2012) both included components of work involving naturalistic driving trials in instrumented vehicles. Of specific interest to this paper was the use of video recordings and digital eye-tracker readings to monitor eye-gaze behaviour. The aim of the study was to describe the results and challenges of applying these two methodologies under real-life driving conditions based on nine subjects from the ADSEAT project and ten from the TeleFOT project. It proved possible to detect the effect of navigation devices on driver attention as reflected in eye-glance behaviour through manual review of video recordings. This procedure was however very labour intensive. While the digital eye-tracker produced reliable measurements of head movements through real-time image processing and recognition of facial features, it generally failed to provide meaningful data on eye-gaze movements. There was however several minutes of remarkably accurate eye-gaze readings found within hours of recording that proved the technology could work if the experimental methodology were perfected. This potentially opens the way to cost-effective analysis of eye-gaze behaviour by the application of computerised algorithms to digital files.

1 INTRODUCTION
The naturalistic driving results reported in this paper derive from two EU projects funded under the 7th Framework. The ADSEAT project ran from October 2009 to March 2013. The objective of the study was to provide guidance on how to evaluate the protective performance of vehicle seat designs in reducing whiplash-associated disorders. As part of this study, driving trials were conducted for nine subjects examining head position as a risk factor for whiplash in rear impacts. The TeleFOT project ran from June 2008 to June 2012 and constituted the largest field operational test of functions provided by in-vehicle aftermarket and nomadic devices conducted to date. This study collected a large amount of data through in-vehicle data loggers and participant questionnaires. One of the aims of the TeleFOT study was to examine the distraction caused by the presence of navigation devices as indicated by changes of eye-gaze behaviour. Of particular relevance to this paper is a series of detailed field operational trials conducted in Great Britain, of which ten subjects are reported in detail.

In both the ADSEAT and TeleFOT studies, it proved quite challenging to obtain the desired quantity and quality of eye-gaze data. Two approaches were adopted, (a) a manual review of video recordings of the driver’s face and eyes to identify the object or field of attention and (b) computerised analysis of the digital readings of an eye-tracking device. The purpose of this report is to give an indication of the results that were obtained and the challenges that were encountered in collecting this type of data.

2 MATERIALS AND METHODS
2.1 Vehicle Instrumentation
The vehicle used for the trials, a 2010 Ford Mondeo sedan, was fitted with three main test instruments: a data logger for vehicle speed, acceleration and GPS location, a FaceLAB™ eye-tracker for head position and eye-gaze direction, and a four-track video system (Figure 1).
2.2 Driving Routes
The route for the driving trials included urban and suburban regions of Leicester, a city with a population of over 300,000 (Figure 2). The drivers' behaviour at nominated intersection manoeuvres was studied in detail.
2.3 Subjects
The nine subjects from the ADSEAT sample comprised five men and four women aged between 23 and 53 years. An impression of the typical seating postures adopted by participants while driving is provided by the snapshots in Figure 3.

Figure 3 Seating posture while driving for nine ADSEAT subjects.

3 RESULTS
3.1 Video review of eye-glance movement
The results in this section had the target of eye movements identified through manual review of the in-car video recording of ten subjects from the TeleFOT project. The objects of attention for the video review were categorized as ‘forwards’, ‘outside’, ‘right or left mirror’, ‘rear-view mirror’, ‘passenger’, ‘instrument panel’ and ‘interior (nfs)’ as pictured in Figure 4.

Figure 4 Description of eye glance surfaces/areas
Figure 5 shows the distribution of glances to all recorded objects or fields of attention as a proportion of total glances made by each participant. The largest group of glances was recorded as ‘forwards’, this category can be described as an eye/head position towards the direction the vehicle is travelling and is bounded by the vehicles nearside and offside A-pillars. This category offers a range of head movement of around 45 degrees, although this is not equally split due to the offset right driving position (see Figure 4). As such, this group may include some head rotation but it is generally recorded when the driver is not looking at any other definable feature. As expected ‘forwards’ glances account for over 90% of glances for most participants with no driver falling below 85%. To eliminate the variance in glances to objects or fields of attention other than forwards, Figure 6 uses the same data as Figure 5 but for all participants combined, therefore creating an average of all the glances made to each location.

Figure 6 shows that apart from ‘forwards’ glances the next most common glance location is to the outside through either the offside or nearside door windows. A glance of this type will induce considerably more rotation of the drivers head, particularly with respect to the nearside door window, than a glance to the forward roadway. Glances to the right-hand door mirror and rear-view mirror are also relatively common but result in much less head rotation and in some cases, depending of driver stature and seating position, can be glanced at with eye movement alone.
In order to identify the effect of the other glance locations Figure 7 and Figure 8 have the ‘forwards’ category removed to give better clarity on the different objects or fields of attention. The chart is ordered to show the largest groups first, namely the areas outside through the side windows followed by rear-view mirror and right-hand mirror (Figure 7). This figure shows clearly that areas that involve extreme head turning, looking at a passenger or around the interior of the vehicle are relatively uncommon and represent the lowest proportion of glances. Data for Figure 7 is for all participants combined but data shown in Figure 4 indicates that there is variance between different drivers. Figure 8 shows the eye glance data for each participant.

![Figure 7](image)

**Figure 7** Proportion of glances to different areas during driving excluding ‘forwards’ (aggregated).

Data for some participants illustrates (Figure 8) that their glance behaviour could influence their head position much more than for other participants. For example participant 4 exhibits a larger proportion of glances towards the passenger and interior which indicates more extreme head turning, whereas participant 7 distributes glances towards objects with lower head rotations such as the rear-view mirror, right-hand mirror and instrument panel.

![Figure 8](image)

**Figure 8** Proportion of glances to different areas during driving excluding ‘forwards’ (by participant).

Data presented in this study is for periods in the video data where the vehicle was moving as this was deemed to be the condition under which distraction (or ‘eyes off road’ glances) was most risky. Glance analysis was also conducted for periods where the vehicle was stopped and data for this
shows some small but possibly significant differences. Although average glance duration of around 0.8 seconds (to all locations combined) was only around 14% greater than the average glance duration in the moving data (0.7 seconds) the clearest change between the moving and stationary periods is the increase in longer glances (greater than 1 second). These longer glances also tended to be to areas outside of the side windows or to the passenger; both of which involved more extreme head turning.

3.2 Digital analysis of eye-tracker readings
The results in this section report the outcome of analysis of the eye-tracker digital readings of nine subjects. The duration of nine driving trials is shown in Figure 9. Periods of missing readings (when the eye-tracker was not able to fix on facial features to assess head position) are outlined at the top of each bar and shaded in yellow where the video was reviewed manually to identify occupant behaviour. The proportion of missing readings ranged widely from almost negligible in case 2 to over half in case 6.

![Figure 9: Duration of driving trials and vehicle movement (by participant).](image)

Approximately 23 minutes of video were manually reviewed for the four drivers with the highest proportion of missing readings while their vehicle was stopped or stopping (Figure 10). This video review clarified the activity of drivers during the periods of missing data within the resources available for the work. Two types of activity were observed to provide the main explanation for the missing data: firstly, rotation of the head beyond the measurable range of the eye-tracker and, secondly, rotation of the head rapidly from side to side, not necessarily beyond the range of measurement of the eye-tracker, but too fast for it to maintain continuous, real-time image processing. These are described as ‘Extreme head turning’ (7 minutes) and ‘Repeated head turning’ (13 minutes) in Figure 10. The explanation for missing readings in the remaining 2–3 minutes was either ‘Other types of head movement’ or ‘Unknown’.
Figure 10  Activity of drivers obtained while vehicle stopped or stopping and digital instrument readings not captured.

Figure 11 show a rare period of perfect eye-tracking recording for a single subject in a continuous transition from one manoeuvre to another. Each glance target has a characteristic shape: instrument panel (‘Inst’), internal rear-view mirror (‘Mir C’), external right mirror (‘Mir R’), front passenger (‘Face’) and the left and right exterior (‘Ext L’, ‘Ext R’). The upper trace showing head rotation is synchronised with the lower trace showing eye-gaze movement. Small breaks in the eye-gaze traces accurately record eye blinks, interestingly on the return from glances to the rear-view mirror.

Figure 11  Successful tracking of eye-glance movement (subject 1006).

The eye-tracker featured an in-built function for assessing the quality of its readings based on real-time image processing. In Figure 12 most of the readings received the highest gaze quality assessment (red line) but in fact bore no useful relationship to reality.
Figure 12  Tracking of eye-glance movement reported as successful but not actually meaningful (subject 2063, sample 1).

Digital readings were missing for many periods of recording. Figure 13 shows an example of readings that were too intermittent to be useful for identifying eye-glance targets.

Figure 13  Intermittent recording of eye-glance movement (subject 2063, sample 2).

4 DISCUSSION
The video review data showed that for majority of the periods analysed, drivers looked ‘forward’ to engage in driving. On average, the participants had their eyes off the normal activity (looking forward) for only 7% of the total test duration, the highest being 13% and lowest 4%. The manual video review process provided good quality information, however it was very time consuming and tedious.

Unlike the digital data collected the video data provides almost 100% coverage of the interior occupant views and exterior contextual views. Although the analysed data consists of only selected sections of a much larger trial (approximately 10 minutes of analysed data from a trial lasting over one hour), these were not selected for the quality of the data but for the road type and layout they contained. This selection methodology indicates that it is likely that the remaining unexamined video data contains similarly good quality glance behaviour to that seen in the examined sections.
Deriving data from video, so called data reduction, is a relatively mature science that is well understood. One aspect of this understanding is that it is very time consuming and the TeleFOT study was no different in this respect. Each data set from each participant contained over an hour of data of which only around ten minutes was analysed; to analyse this ten minutes and reduce the video down into a form which can be easily used took around one working day (or approximately ten hours). Understandably, issues with analysing larger data sets in this way leads to huge time constraints and many working days to achieve.

One limitation to the approach of analysing glance behaviour from video is that it provides data that is reliable but does not necessarily provide data that is of high clarity. Data for glances towards the forwards roadway for example will be very reliable—i.e. the analyst will be very sure the driver was looking forwards—however it might not be possible to determine whether that forwards glance was to the right or left of centre or what further information such as the driver’s head position during the forward glance.

Analysing the TeleFOT data indicates that drivers do control their glance behaviour. Observed glance patterns for periods where the vehicle was moving differed from the patterns where the vehicle was stopping or stationary. In this latter period glances tended to be towards areas that were out of the side windows with more extreme head movements or they tended to be of much longer duration. This indicates that as the driver begins to bring the vehicle to a stop and subsequently when the vehicle is stationary, they perhaps see less risk in this glance behaviour.

Missing data from ADSEAT is predominantly in the ‘repeated head turning’ or ‘extreme head turning’ categories and is a result of the technical limitations of the eye tracking equipment. It is likely that this missing data is particularly associated with periods where the vehicle is stopping or stationary as observed in the TeleFOT video analysis.

The eye-gaze readings shown in Figure 11 were quite exceptional for their quality and rarity in the ADSEAT and TeleFOT studies. Subject 1006 recorded several minutes of perfect data under demanding driving conditions that included fluctuating light intensity, large movements of the head and upper body, and vehicle acceleration, braking and turning. Some similar quality data was found for a couple of other subjects but only for a few seconds. In these cases the good readings occurred at the beginning of the driving trial. Most of the eye-gaze data for the tens of hours of trials was either (a) missing or excessively intermittent (Figure 13) or (b) impossible to relate to reality despite being reported by the eye-tracker device as being of good quality (Figure 12). The conditions that disrupted eye-gaze recording are not fully understood, nor is it known why no data of intermediate quality appeared—it was either perfect or entirely unusable.

The recording of head position and rotation from the eye-tracker relied on recognition of facial features but, unlike gaze direction, did not depend on real-time image processing of the eye, particularly the iris and pupil. Head position readings were far more robust than eye-gaze readings and supported a substantial analysis of digital data for the ADSEAT project. A corresponding analysis of digital eye-gaze data as an indicator of driver distraction could not however be carried out for the TeleFOT project.

5 CONCLUSION
Manual video review produces results but demands high resources (time, labour, cost). Digital processing potentially automates the analysis but perfection of experimental techniques or application of newer technology required to obtain suitable data.
6 REFERENCES