

Are We Looking Where We are Going? An Exploratory Examination of Eye Movement in High Speed Driving

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ABSTRACT

This paper reports on results of an exploratory study aimed at examining driver glance behaviour, near the onset of and during congestion on motorways and how it is affected by factors external to the vehicle. Data has been collected on eye movements from six test subjects, each undertaking three test drives. Analysis has examined average glance times and fraction of time spent looking into a number of broadly defined areas. The study has revealed that on the whole drivers spend 80% of their time looking into a 'forward' area and, on average, look away from the forward scene for around 0.65 sec. at a time. In addition to variations between subjects, factors such as road section were found to contribute to variation, however no firm dependence on the level of traffic flow was found. It is hoped that this exploratory study has helped to reveal a number of 'baseline' dependencies regarding glance behaviour, and further, that this information will be of use to a range of fields, from the design of in-vehicle telematics systems, through to simulation science.

BACKGROUND

Everyday driving is becoming an increasingly demanding activity, with an abundance of rich information sources placing a strain on the driver's limited attentional resources, ranging from those in the driving environment (e.g. road signs) to those within the vehicle (e.g. in-vehicle navigation systems). Regardless of the source of distraction, it is becoming ever more important to understand where a driver's attention is directed, and how it may vary due to 'external' factors (such as traffic flow, merging vehicles etc.) as well as 'internal' tasks within the vehicle (monitoring speedometer etc.). In addition to providing a normative safety indication that could be used in accident predictive modelling (*1*) and in the assessment of the impact of Intelligent Transportation Systems (I.T.S.), this information is also of importance to driver simulation modelling where avoiding incorrectly modelled, overly attentive drivers, may be of key importance in correctly simulating road traffic and all its inherent instabilities.

Studies on such glance behaviour have now been performed for over thirty years (e.g. *2*), and there are now a great many in print. Work has covered almost all features of driving behaviour, with particular emphasis having been placed on, for example, glance behaviour while cornering/steering (*3, 4, 5, 6*) and the effects of I.T.S. and the distractions that they may cause (e.g. *7, 8*). A number of normative studies have also been performed to examine driver visual search patterns in relation to specific driving tasks, such as reading signs (*9*), splitting attention between differing objects in the forward view (e.g. *10*), and how visual search varies with differing types of street environment/road design and speed limit (*11, 12, 13*), or within the vehicle in use of vehicle controls (*14*).

It is this wealth of studies on driver glance behaviour as a whole however that has given rise to the perceived belief that this is a well explored and documented area. However, this is not so, and in particular there is little information regarding how drivers normally spread their attention, between in-vehicle elements and out of vehicle features during the course of normal (straight line) driving and how this relates to the immediate traffic environment and in particular, congestion, and the density of the surrounding traffic. Although such data exists in most cases this has been collected using simulator based methods (*15*), which may cause substantial differences (*14*). Indeed, to quote the excellent review by Green (*16*) to which the reader is referred for detailed examinations of many of the above issues, "the number of studies that involve driving in traffic has not been overwhelming".

It is the intention of this paper therefore to attempt to measure normative glance behaviour for a small number of subjects using in-situ measurements to establish what external factors (on the macroscopic scale) may effect glance behaviour.

DATA COLLECTION

Data used for this study was collected using the Transportation Research Group (TRG) instrumented vehicle (17) which is a 2 litre sedan car equipped with sensors capable of measuring ground speed; distance to adjacent vehicles through automotive radars; use of pedals (all at 10hz); and recording video pictures of the driver, rear, and forward views (Figure 1).

The test route used was a three lane motorway (70mph (113kmph) speed limit), from Junction 1 to Junction 5 of the M27 to the North of the City of Southampton in the U.K., a total of 16.75km in each direction, split into four roughly equal functional sections, two Westbound (Sections A and B) and two Eastbound (C and D) as shown in Figure 2, with sporadic queuing taking place on sections B and D during peak periods. Data was collected on six subjects, recruited from University staff, all of which were required to have normal eyesight, to have held a driving licence for at least one year, to have had experience of the roads to be driven and to have participated in experiments using the instrumented vehicle before. (This latter requirement is part of an on-going plan to establish a wide range of detailed metrics for a small number of subjects by undertaking limited 'scoping studies' such as that reported in this paper). Each was given a one-off payment of £30 for participation in the experiment. (5 males, 1 female, aged between 29 and 54, average age 41 with normal vision). Subjects each undertook three test runs of the course (accompanied by an experimental supervisor seated in the rear of the vehicle), one at lunchtime (approx 12:30-13:30, 'low' flow) and two during the evening peak (approx 17:00-18:00, 'higher' flow), with each run consisting of several laps of the test course.

For each of the test runs, data was manually transcribed from video records (with an accuracy of 1/25th sec.) regarding when a driver switched his attention between five regions demonstrated in Figure 3: Down (DOWN, looking into the interior of the vehicle, speedometer, vehicle controls, radio etc.), Left (Passenger Side) Mirror (LEFT), Right (Driver Side) Mirror (RIGHT), Rear View Mirror (UP), Ahead (AHEAD) and 'Other' (OTHER, where a clear determination was not possible). In each case, times recorded were from when the driver was clearly looking into a particular region, and hence times in regions, calculated from differences in consecutive times, include time spent in motion out of each region. An example of the differences observed in average times spent looking into differing regions for one such set of responses is given in Figure 4.

DATA ANALYSIS AND RESULTS

Two primary indicators have been extracted from the data collected, Average Glance Time per region (AGT, sec., the average of uninterrupted glances into each region) and percentage of total time in each region (%T, %). Each of these has been analyzed according to four independent variables: section (SECTION, A-D), subject (SUB), time of day (TOD, lunchtime vs. evening) and flow (FLOW, vehicles per hour, a covariate). Flow measurements used for each section at the appropriate time of day, are provided from a scaled five minute count from one induction loop in each section producing a count for vehicles over all three lanes in total. Although highly approximate it is felt that this average at least provides some suitable surrogate of the overall conditions experienced, linking SECTION and TOD (see Figure 5). (The measurement only truly represents the flow over a particular five minute period at a particular point. Hence its relevance to the flow experienced by each vehicle as it progresses further down the section diminishes over time). FLOW itself indeed, can be predicted well by the use of the SECTION and TOD variables, providing, (along with the use of a second level interaction term) a predicted fit to the measured data with an r^2 of 0.78, with all terms significant at the $p < 0.001$ level. For this reason, the analyses undertaken using the four independent variables has excluded the three second-order terms between SECTION, TOD and FLOW.

Percentage of Time in Each Region

A first analysis of %T (Figure 6) reveals that each driver is spending around 80% of their time looking AHEAD with around 6% of the time observing the rear view mirror (UP), and additionally there is only a small variation in these splits across the subjects (Figure 7).

A more detailed investigation is hampered to some extent by both the small sample size and the correlated nature of the residuals for the analysis of the %T for each zone. However we are able to focus our analysis on examining the split between percentage of time spent looking AHEAD, and percentage of time looking elsewhere (all the other zones combined). Here, we are able to perform a logistic analysis to describe the effect of each of the independent variables on this factor, with results given in Tables 1 and 2. We see that there are clear inter-subject variabilities as well as dependencies on SECTION, SUB*SECTION and SUB*FLOW. However the variability caused by these factors in combination is exceptionally small, exhibiting variations about a base value of 71.5%, of around 5% due to SUB and of around 4% according to FLOW and SECTION for 'medium' flows.

Average Glance Times

A complementary indicator to the percentage of time in each region is that of the average glance time for each region (AGT, Table 3). The first and most noticeable factor affecting glance durations in all regions is that of SUBJECT where a highly significant difference is apparent as demonstrated in Figure 8. Secondly, SUBJECT effects aside (producing a variation between, 0.35 and 1.02 sec.), none of the independent variables significantly affect AGTs to the LEFT mirror. The remaining interactions are subtle however and, subject effects aside, may be summarized as follows:

Looks into the car (DOWN) are distributed about 0.61 and affected by TOD (although with a very small magnitude of <0.007 sec.), SUBJECT (intra subject effects of +0.08 to -0.08 sec. in five of the six cases) as well as to a lesser extent by SUB*FLOW (approx. $2-6 \times 10^{-5}$ sec/vehicle per hour, which for commonly encountered flows of 3000 to 6000 vph corresponds to an additional 0.06 to 0.36 sec.). In summary, the only appreciable variation for DOWN glances occur for some subjects at higher flows, where the glance times may increase. This is rather surprising as if anything, the amount of time spent looking away from the road as the situational complexity of the driving task increases, would be expected to decrease.

RIGHT mirror durations vary according to subject from 0.47 to about 0.73 sec., and are only affected by SECTION and to a lesser extent by TOD*SUB. SECTION contributes up to an additional 1/20th of a second or so (additional glance times of 0.07 sec. for Section A, 0.05 for C and 0.04 for B) and may be explained by the fact that several of the lane changes to this side on sections A and C are required after merging onto the motorway when moving into the desired lane. (With a greater speed differential existing between host and surrounding vehicles, greater attention may be required). The effect of TOD*SUB is to vary lunchtime averages by -0.02 to 0.1 sec.. It is noticeable that this TOD based effect also occurs for other out-of-vehicle AGTs and is dealt with below.

UP (rear view mirror) glances vary from 0.46 to 0.82 sec. and are, in common with the results presented above, affected by TOD and TOD*SUB (combining in four of the six subjects to produce a glance time change with a magnitude of less than 0.02 sec., but in two others, reducing glance times for the lunchtime run by around 0.12 sec.). SUB*FLOW also affects times, causing a variation of -1.5 to $+3.6 \times 10^{-5}$ sec/vehicle per hour, corresponding to -0.09 to 0.22 sec. for commonly occurring flows. This slightly greater glance time in higher flow conditions may be caused by the increased attention that needs to be paid to the vehicle to the rear to ensure that the host vehicle is not improperly 'hogging' the lane, and to maintaining a knowledge of the following distance adopted by the vehicle to the rear, which may be instrumental in determining braking levels should any 'hard' deceleration be required.

Glance times AHEAD show an intra subject variation of 2.69 to 5.76 sec. affected by SECTION (around 0.24 sec. shorter on Section C and 0.22 sec. greater on Section A), and TOD and

their 2nd level interactions with SUB. In common with AGTs for other out-of-vehicle glances, the average time for each glance ahead is affected by TOD, but conversely, with glances being 0.74 sec. longer during lunchtimes. The 2nd order interaction terms of SECTION*SUB and TOD*SUB produce a complex pattern of interaction with glance times generally shortening for most subjects by 0.22 to 2.19 sec., notably more so for sections A and C, and for lunchtime runs by 0.40 to 1.84 sec. (it is interesting to note that no response to FLOW is observed, as it could be hypothesized that with increasing flow longer fixations would be required on the road ahead).

The recurring presence of TOD effects in the above analyses may be interpreted as a reflection of visibility conditions. With the rush hour runs being conducted in lower light conditions, an accurate estimation of the distance and relative speed of surrounding vehicles may have become more difficult requiring greater concentration by some drivers in key situations such as judging gaps in passing manoeuvres. However this does not explain the fact that the opposite effect occurs for glances AHEAD. One potential explanation is that 'all' observations do indeed require longer glance averages but with only a finite time resource available tradeoffs must be made, and, with the visual search required in car following being less, and the decision making structure being simpler (if brake lights are seen then decelerate, for example) increases in AGTs to REAR and RIGHT are made at the expense of AHEAD.

DISCUSSION AND CONCLUSION

In this paper we have analyzed the variability of glance times into five regions, the percentage of time that the driver looks away from the forward view, and how this is affected by a number of macroscopic variables (such as flow and section for example). In many cases we have found a complex and significant pattern of interaction, noting in particular that there are significant interpersonal differences in all areas and that section (of the test course) and time of day, produces significant effects in many cases. However, in the majority of cases no effect due to flow has been determined.

Finding comparable figures against which to judge our results is difficult, with the majority of studies having investigated the interaction of the driver with differing information sources, using different methodologies or measuring differing dependant variables. Due to this, the most comparable figures available concern average look down times into the vehicle, where we find that estimates exceed our average of 0.53 sec., varying from 0.66 (15 - for the 'expert' driver group), 0.77 (18 - for the 'experienced driver' group) through 1.05 sec. (19), to 1.27 to 1.42 sec. (20). The longer times found by others are perhaps due to the fact that their findings concern solely glances to specific controls, such as operation of the radio for example, which will necessitate greater attention than for example glancing at the speedometer. Views to the drivers' side mirror range from 0.56 sec. (21), through 0.64 sec. found in our study, to 0.98 sec. (18 - for the 'experienced' group), 1.17 (19), to 1.06 to 1.22 sec. found by Rockwell (20). Still less information is available concerning glances to the rear view mirror with our figure of 0.67 sec. being broadly comparable with that of 0.87 sec. found by Mourant and Rockwell (18 - 'experienced' group) and the 0.92 sec. from Lansdown (15 - 'expert' group).

Concerning the fraction of time spent looking into each region, even less information is available to us, with perhaps the only source being that of Carter and Laya (22) who measured percentages of glances in both straight line driving and in overtaking situations. Direct comparison is therefore difficult, however ranges of 0.3-4.3% of time was spent looking at the rear view mirror, 1.0-4.1% at the drivers side mirror, 6.8-13.4% into the vehicle (at the dashboard), compared with 6.3%, 4.7% and 1.8% respectively in our studies. Percentage of time spent looking into the AHEAD zone however may only be directly be compared with figures from Mourant, Rockwell and Rackoff (23) who quote a figure of 86.8%, Lansdown, Parkes, Fowkes and Comte (15) who quote 93.6%, while a more comparable study (19) quotes 81%, very close to our figure of 80%.

In the majority of the above cases we are finding that the figures available for glance times and percentage of time looking into the vehicle are larger than our own while conversely, in our study drivers are spending more time using the mirrors but with slightly shorter average glance times. Such differences however may be expected as our data was collected on a real road over a wide range of flow conditions, while others were collected (in most cases) undertaking a simple car following task on a test track. With the increased richness of the traffic situation present in real driving, an increased awareness of surrounding traffic would obviously be required, necessitating greater attention to locating and tracking surrounding vehicles visible in mirrors at the expense of looks into the vehicle.

A more interesting comparison however may be made with related values calculated in a comparable study by Tijerina (21) who also reports an average duration of glance away from AHEAD of 0.6 sec., that, while below that of Rockwells' (1.06 sec.), is more in line with our own at 0.65 sec. and is again perhaps an artefact of a richer driving task (in Rockwell's experiments there was no lead vehicle and hence attention could more easily be taken from the front view).

There are differences between our studies and Tijerinas' however, who finds for example that the number of glances away per following sequence is constant at 1.84 ± 0.17 per second of following, over age, sex, vehicle type and rush hour vs. non rush hour traffic (corresponding to one glance away every 5.9 sec.). Direct comparison again is not possible as following vs. non-following is not recorded in our database, however using all the data available an analogous rate of glances away per second of 0.29 may be found ($r^2=0.40$), corresponding to one glance away every 3.4 sec.. Our drivers would seem to be undertaking a much more active visual search of the driving environment, although this may be explained partially by the fact that Tijerinas' subjects were instructed and monitored solely during car following, necessitating a more greater attention on the vehicle ahead. Additionally there are differences in the split of glances immediately following a look ahead with our figures being higher for glances to the rear view mirror (44.9% vs. 27.4% for the 'middle' group of ages, 35-55) and for glances to the drivers' side mirror (35.3% vs. 17.9%), while lower for the offside mirror (5.4% vs. 9.5%) and into the vehicle (14.3% vs. 35.0%).

Perhaps the most notable finding of the Tijerina study however, was that glances away from AHEAD were independent of typical car following parameters such as following distance (in time or distance) or relative speed, both in terms of the duration of the look away and in its timing, factors that have not been examined in our study. This forms an interesting counterpoint to our findings, which in essence state that glance behaviour is for some subjects, independent of flow. Clearly it would be incorrect to view this as a clear finding when so few subjects participated in our experiments, and can only be confirmed following studies with greater subject numbers (although of the six studies cited earlier only two have used more than eight subjects). However, when viewed together it does present the possibility that glance behaviour may be independent of the dynamic state of the traffic and instead more dependent on the type of task being undertaken and environmental factors, such as time of day, and (perhaps geometric) characteristics of the road along which the vehicle is being driven.

Clearly, there are a number of experimental confounds which restrict the usefulness of our data. Our subjects represent a small sample, clearly have a male bias and are drawn from only one age group (although in the comparisons above we have attempted to compare with compatible age bands in other studies). While there is little information on differences between sexes (none are revealed in the references cited in this section), it is possible to say a little regarding potential age effects. It has been shown (e.g. 24) that more experienced drivers are on the whole more 'focused' on the task and demonstrate shorter fixation times, a factor that may explain some of the differences between our values and those from other sources, although in many cases, age effects have on the whole not been explored or stated.

This study clearly only presents a partial picture of driver glance behaviour and we have not for example (due to methodological constraints) attempted to analyze the distribution of glances within the AHEAD zone itself (for example while looking forward it is clearly possible to be looking away from the vehicle in-front, tracking the edge of the road). It has however served to illustrate that

glance behaviour forms rich and diverse patterns that need to be more clearly described at the baseline before we attempt to examine any changes that may be caused by technology. For example, there are many differences between our data and other sources, the nature of which are clouded by issue of experimental instructions, types of course, even national differences due to training/licensing requirements, and we hope to attempt to harmonize these differences by the use of more advanced collection and indeed analysis methods (25) in forthcoming work. However to quote Green (16), “without such [baseline] information, making decisions about what is atypical .. or unsafe is a challenge”.

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FIGURE 1 TRG Instrumented vehicle (Upper), Sample Video Image from a Test Run (Lower)

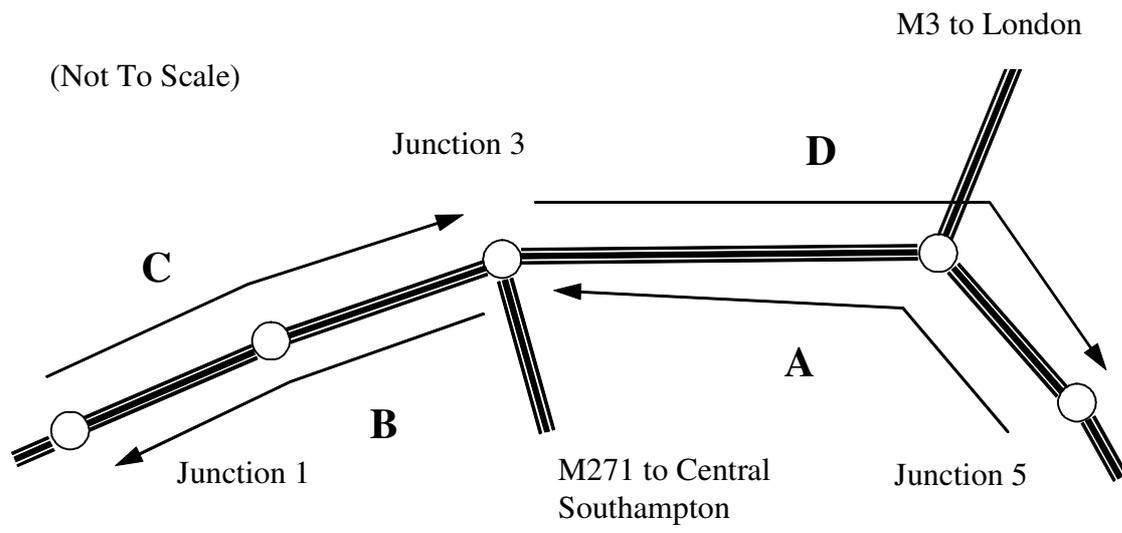


FIGURE 2 Delineation of Test Route

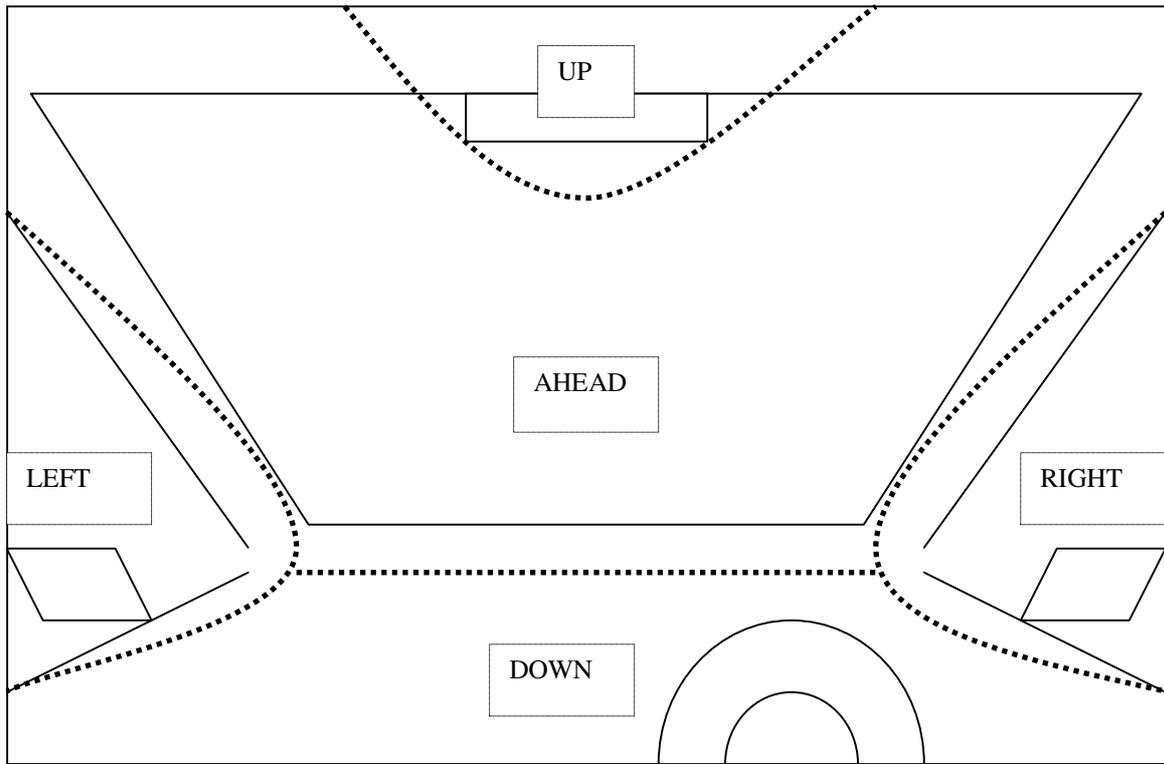


FIGURE 3 Classification of Glance Areas

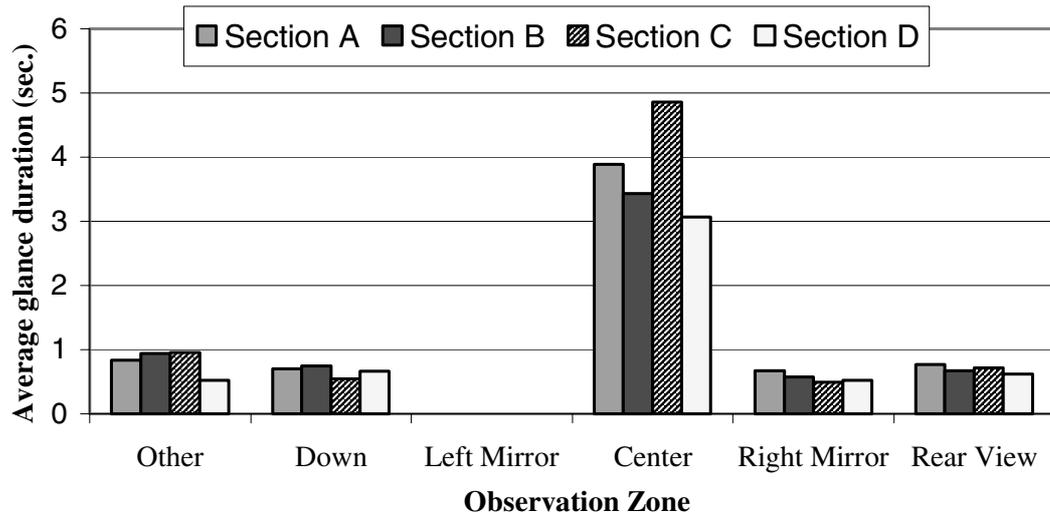


FIGURE 4 An Illustration of the Variability of Average Glance Times for One Subject Over the Course of One Test Lap.

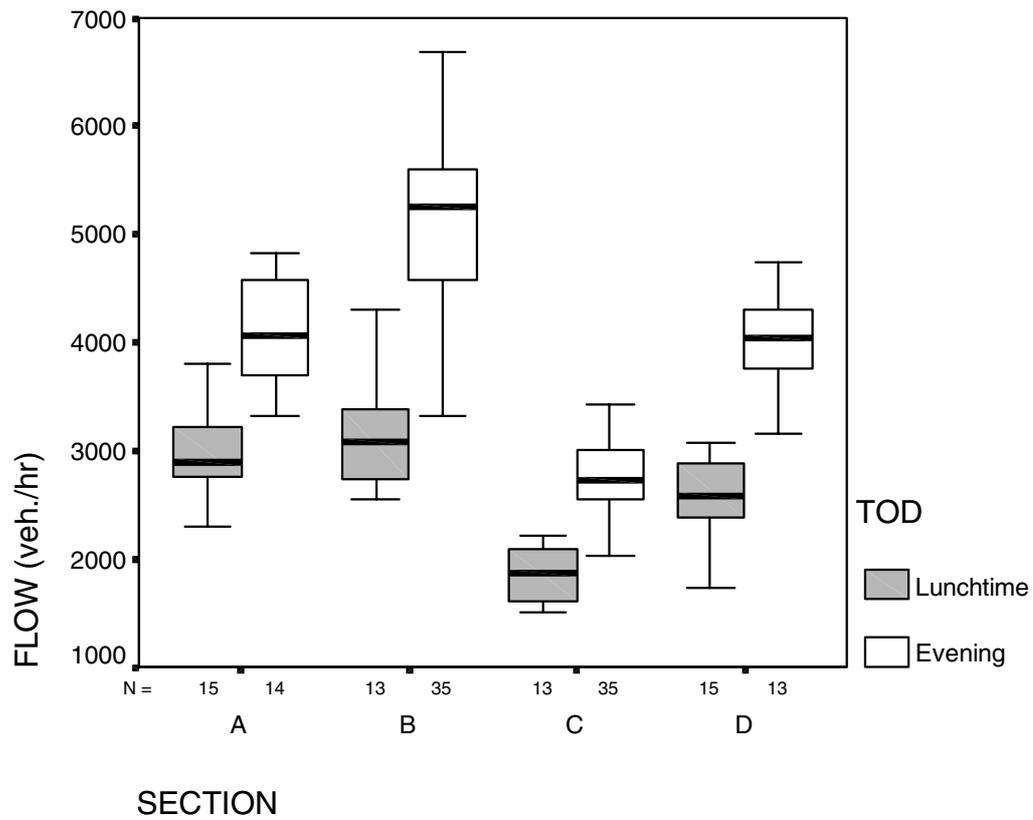


FIGURE 5 Inter-relationship Between FLOW, SECTION and TOD

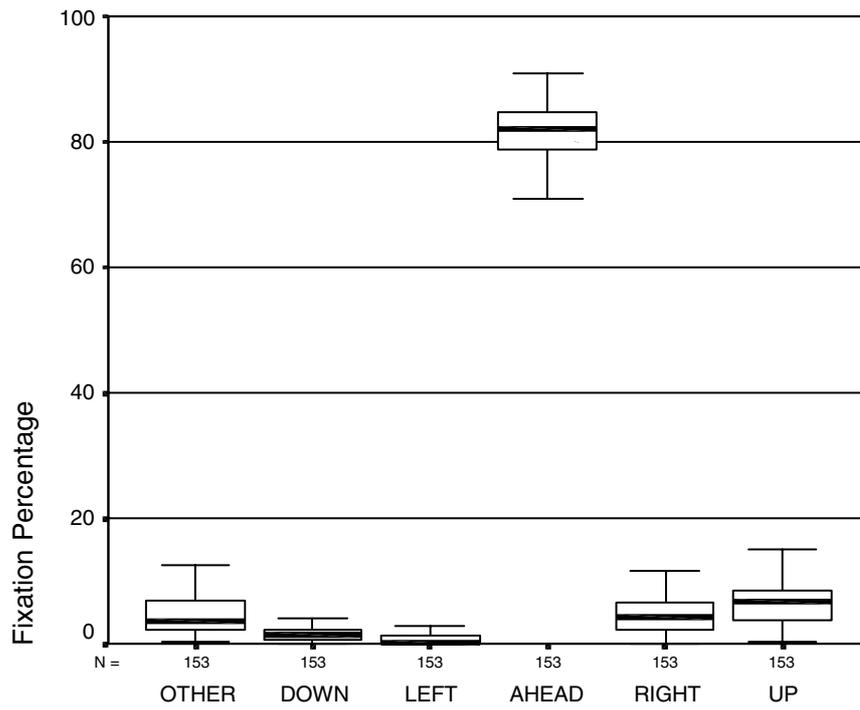


FIGURE 6 Average Fixation Percentages

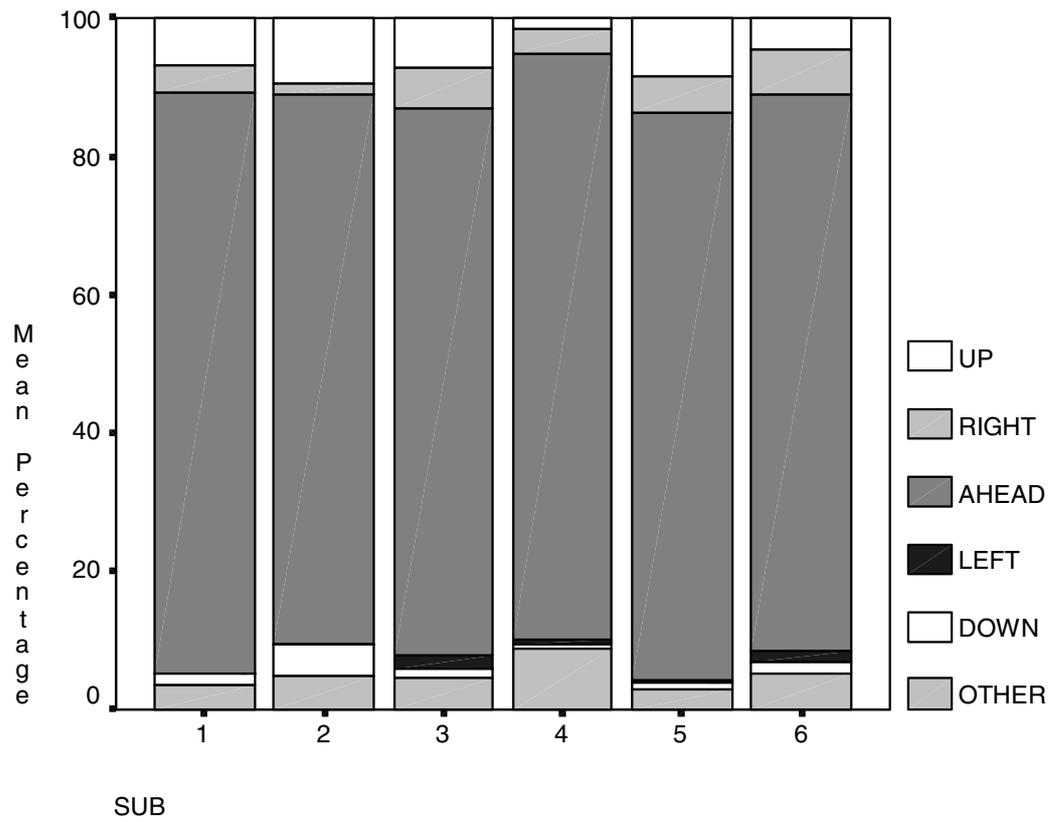


FIGURE 7 Mean Fixation Percentages by Region and Subject

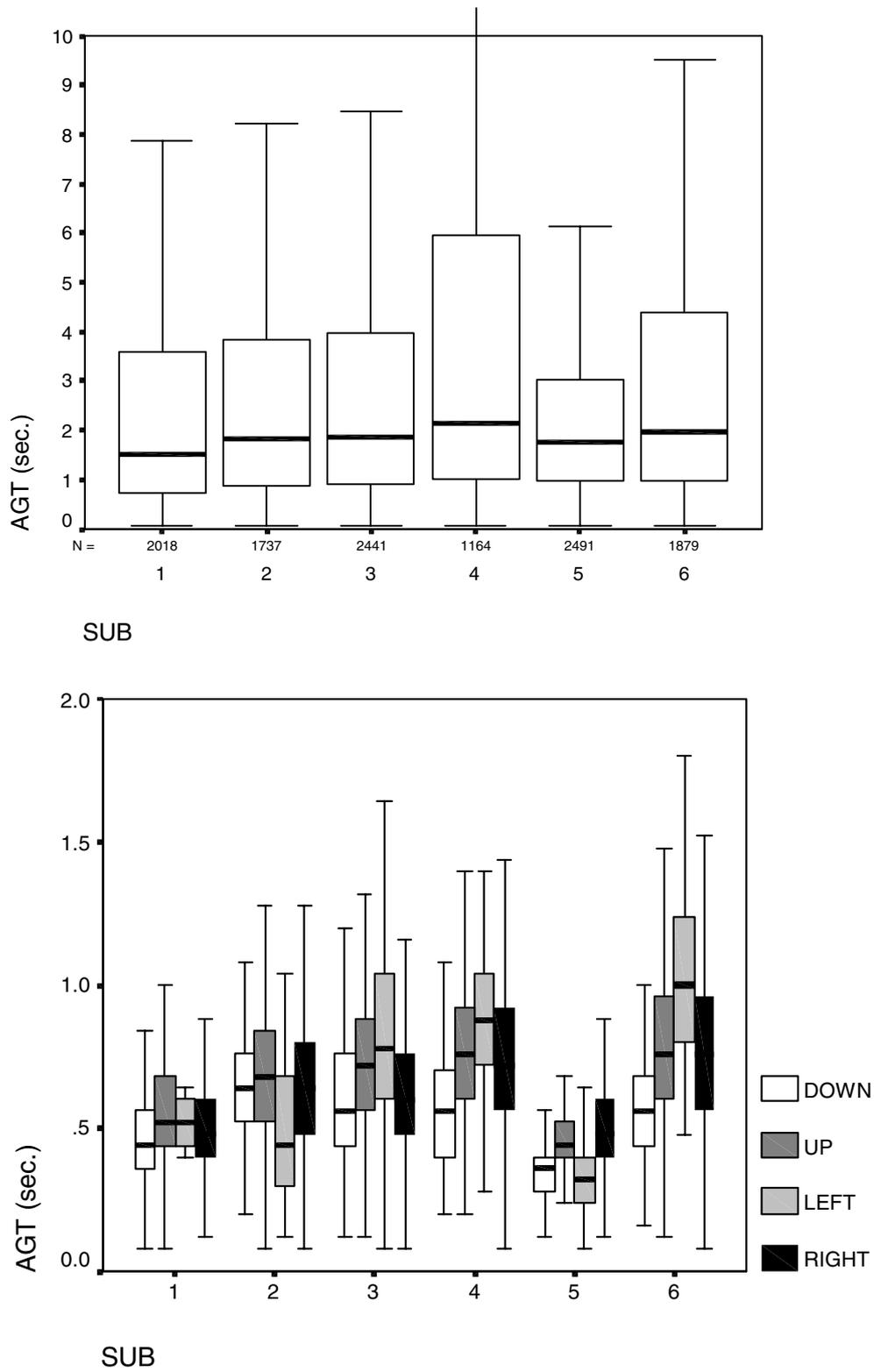


FIGURE 8 Differences in Glance Times by Subject. Ahead (Upper), Other Zones (Lower)

Source.	SECTION	TOD	SUBJECT	FLOW
SECTION	<0.001**	N/A	0.008**	N/A
TOD		0.242	0.619	N/A
SUBJECT			<0.001**	<0.001**
FLOW				0.964

** Variables reaching a level of significance of $p < 0.01$.
 $r^2 = 0.615$

TABLE 1 Results of Logistic Significance Tests for Percentage of Glance Time Spent Looking into AHEAD Zone

Parameter Values	Main Effect	SECTION	FLOW
SUB Max.	0.0736	0.0341	4.22×10^{-5}
SUB Min.	-0.1680	-0.0784	-2.212×10^{-5}
SUB Ave.	-0.0299	-0.0141	1.404×10^{-5}
SECTION Max.	0.0008		
SECTION Min.	-0.0386		
SECTION Ave.	-0.0094		

Intercept = 0.921

TABLE 2 Parameter Estimates from Logistic Model for Percentage of Glance Time Spent Looking into AHEAD Zone

Variable	Region					
	LEFT	DOWN	RIGHT	UP	AHEAD	OTHER
SECTION	0.145	0.053	<0.001**	0.597	<0.001**	0.472
TOD	0.141	<0.001**	0.688	0.003**	0.003**	0.666
SUBJECT	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
FLOW	0.502	0.109	0.176	0.346	0.542	0.832
SECTIONxSUB	0.330	0.108	0.191	0.769	<0.001**	<0.001**
TODxSUB	0.086	0.683	0.022*	<0.001**	<0.001**	<0.001**
SUBxFLOW	0.691	0.038*	0.290	0.013*	0.749	0.874
Maximum r^2	0.213	0.177	0.147	0.213	0.047	0.089

*Significant at the $p < 0.05$ level

**Significant at the $p < 0.01$ level

TABLE 3 Results of ANOVA Significance Tests for Average Glance Times into Each of Five Differing Regions