Work 41 (2012) 4900-4906
DOI: 10.3233/WOR-2012-0783-4900
IOS Press

What does a motorcyclist look at while driving at urban arterials?

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Abstract. To design adequate measures for enhancing riders' safety, a necessary first step is to understand the riders' visual scanning strategies under different traffic conditions. This paper presents the preliminary analysis of eye tracking data collected by three riders in the Athens metropolitan area, riding along urban arterial motorways and along an undivided urban road. Apart from the fixation duration and location, the fixated road elements and specific objects were annotated and analysed. The mean duration of fixations was found to be higher on urban roads than on motorways for all traffic densities. Riding in the condition of restricted flow seems to be more demanding for the riders, since the mean duration of fixations was higher in restricted flow than in free or congested flow on motorway and also higher than in free flow on urban road. The riders' fixation locations differed between motorway and urban road, especially in the vertical plane. The analysis of fixated road elements and specific objects indicates the specific points of interest of riders in each case. Although results should be validated with data from more riders, they provide hints on direction of future research efforts to enhance riders' safety in urban environments.

Keywords: Motorcycle riders, Visual scanning, Mean fixations locations, gaze angle, urban traffic

1. Introduction

A lot of research effort has been devoted to the analysis of drivers' visual scanning behaviour in order to understand the driver's processing of the visual scene. It has been reported that the drivers most often fixate near to the focus of expansion with regular excursions to items of road furniture, road edge markings and other vehicles (Mourant & Rockwell, 1970). In more complex visual scenes eye movements increase in number while their mean fixation duration decreases (Miura, 1990). Mean fixation durations when drivers view films of rural roads tend to be longer than when viewing urban ones and when dangers are present (Chapman & Underwood, 1998). When negotiating curves, drivers adjust their fixation locations so as to maximise their sight distance and provide information about the future curvature of the road (Helander and Soderberg 1972; Shinar et al 1977), for example they fixate on the tangent point made by the driver's line of sight ahead to the inside of the curve (Land and Lee 1994), or they gain information about lane position from closer to the current position of the vehicle for accurate curve following (Land and Horwood 1995; McLean and Hoffmann 1973).

Research on motorcycle riders' eye movements is less common. A few studies have compared the visual scanning patterns of riders and drivers, showing that they differ significantly. Analysing eye tracking data from three male participants, Nagayama et al. (1980) report that motorcycle riders have a wider vertical distribution of fixations than car drivers and they fixate more frequently on the road surface, both near and far, while car drivers fixate more often at or above the horizon, at objects such as traffic lights and seldom at the road surface. Tofield and Wann (2001) report that motorcycle riders fixate significantly fur-

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ther down the road than car drivers with no motorcycle riding experience. As regards riding experience effect, Hosking et al. (2010) report that in simulated motorcycle riding experienced motorcycle riders have a more flexible visual search pattern than inexperienced riders. Underwood and Chapman (1998) report that motorcycle riders have fewer fixations on hazards than car drivers.

The previous research efforts relevant to motorcycle riders were not always based on data collected from real traffic and have not analysed the exact objects on which the riders fixate under different traffic conditions. Possible measures to enhance riders' safety within urban environment are the design improvements of infrastructure, better riders' training and the design of adequate systems supporting riders in the identification and handling of possible risks. To implement such measures, a necessary first step is to understand what the visual scanning patterns of experienced and inexperienced riders are and which types of objects draw the riders' attention. Therefore, the objective of this study was to analyse the visual scanning strategies of experienced riders in real traffic conditions within an urban environment and to examine if these are affected by the urban road type and traffic density. Another objective was to identify the objects on which the motorcycle riders fixate and to evaluate whether they are different on different road types and in different traffic flow densities. This paper presents a preliminary analysis of first data collected by three riders and gives some first insight on the direction of future research.

2. Method

Three middleweight motorcycles were ridden in the Athens metropolitan area, along the Katechaki and Mesogeion urban arterial motorways with three lanes per direction and a central barrier and along an undivided, one-lane per direction urban road. The motorcycles were ridden by three experienced male riders, mean age 30, mean riding experience 10 years. The riders were instructed to ride as they would normally do. The experiment was conducted in May 2011, at daylight with good sunny weather conditions.

The road type, motorway or urban road, was used as the main independent variable, while the effect of traffic flow density was analysed by annotating each fixation as occurring in free, restricted or congested flow. Free flow was defined as the condition when there was no other vehicle in close proximity to the motorcycle. Restricted flow was the condition when there were vehicles in close proximity to the rider and the rider would have to coordinate his/her planned trajectory to theirs. Congested flow was the condition when there was a traffic jam on two adjacent lanes and the motorcycle was riding in between them, a driving behaviour which is common in the Athens and other metropolitan urban areas.

During the ride the riders were wearing the SMI iView XHED2 eyetracking system with a 50Hz sampling frequency and gaze position accuracy less than 0.5^{o}. This system records the traffic scene from the rider's point of view and identifies the rider's fixations points. The scene is then played-back off-line with the identified fixation points overlaid to the traffic scene. The system also stores the x and y coordinates of each fixation point and its duration. From these data, the gaze angle (Hosking et al, 2010) has been calculated, which is defined as the angle at the observer's eye in the right triangle defined by the eye, the center of the screen which corresponds to the centre of the field of vision, and the fixation point at the x-axis or y-axis at a Cartesian coordinate system. Using the centre of the screen as starting point, the x-angle becomes positive as participants look further to the right and negative as they look to the left. The y-angle becomes positive as participants look further ahead in the field of vision and negative as they look lower, closer to the front wheel of the motorcycle. For the analysis, all video scenes where the rider's head had turned to the right or left because the rider was not looking straight ahead have been eliminated. Considering that the small head movements to the right or left are equally counter-balanced, one can assume that in general the rider's head direction in the video scenes kept for analysis coincides with the axis of the motorcycle.

Three experienced observers watched the videos and annotated for each fixation the specific road element fixated, using the following categories: Right side out of road, Right road edge, Emergency or bus lane, Lane marking between bus lane and first lane, First lane from right, Lane marking between first and second lane, Second lane from right, Lane marking between second and third lane, Third lane from right, Fourth lane from right, Central road barrier, Lane marking between opposing lanes, First oncoming lane, Second oncoming lane, Road (general), Left road edge, Left side out of road. The annotation Road (general) corresponded to fixations further away on the horizon which could not be annotated to a specific road element. The observers also annotated the fixated object, for example Passenger car ahead, Motorcycle, Stopped passenger car, etc.

T-tests were used for analyzing the effect of road type and flow density on fixation duration and gaze angle and chi2 tests were used for analyzing differences among fixated road elements and fixated objects per road type and flow density.

3. Experimental results

3.1. Mean duration of fixations

The total sample, that is the fixations of all three riders together, consisted of 2662 fixations on motorway and 933 fixations on urban road. The distribution of fixations per road type and flow density is shown in Table 1.

Table 1

Number of fixations in the sample per road type and flow density

Sample size in	Motorway	Urban road
Congested flow	1071	243
Free flow	1100	401
Restricted flow	491	289
Total sample	2662	933

The mean duration of fixations (shown in Figure 1) was higher on urban roads than on motorways, and this difference was significant in the total sample (p<0,01), in congested flow (p<0,01) and in free flow (p<0,01) but not in restricted flow. Regarding the effect of flow density, on motorway the mean duration of fixations was significantly higher in restricted flow than in congested flow (p<0,01) and than in free flow (p<0,01) while there was no difference between congested and free flow. On urban road the mean duration of fixations was significantly higher in restricted than in free flow (p<0,05), while no other significant flow effect was found.

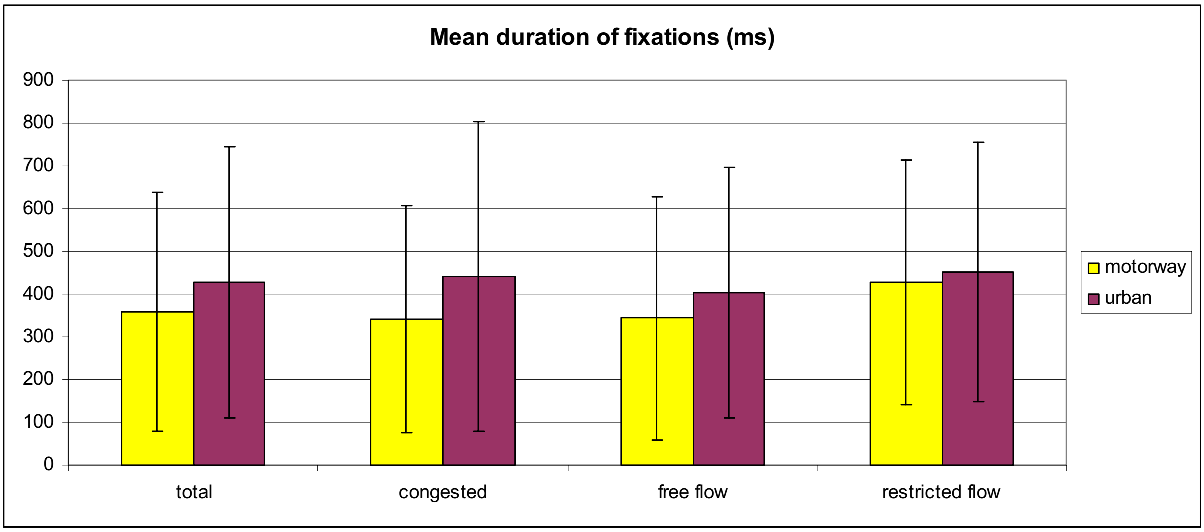

Figure 1 - Mean duration of fixations per road type and flow density

Gaze locations

The mean and standard deviation of the gaze angle in the x- and y-axis are shown in Table 2. Regarding the gaze location in the y-axis in all flow densities the participants looked more towards the center of the field of vision on urban road while on motorway they looked lower, more close to the front wheel of the motorcycle (congested flow p<0,01, free flow p<0,01, restricted flow p<0,05). Regarding the gaze location in the x-axis, some differences were found between motorway and urban road. In congested flow participants looked more towards the center of the field of vision on motorway than on urban road (p<0,01), while on the contrary in restricted flow they looked more towards the center of the field of vision on urban road than on motorway (p=0.001). No other difference between motorway and urban road was found for the x-axis location.

Table 2

Gaze angle (^{o}), mean and standard deviation, per axis, road type and flow density

		x-axis (horizontal plane)		y-axis (vertical plane)	
		Mean	SD	mean	SD
Motorway	Congested flow	2.896	7.569	-4.924	3.612
	Free flow	2.773	7.100	-5.879	3.416
	Restricted flow	2.530	6.641	-5.655	2.823
	All fixations	2.778	7.211	-5.453	3.425
Urban road	Congested flow	5.248	8.261	-1.583	3.233
	Free flow	2.792	6.028	-4.822	2.179
	Restricted flow	1.061	4.798	-5.186	2.667
	All fixations	2.895	6.551	-4.091	3.032

On motorway no effect of flow density was found on the gaze location on the x-axis. Regarding the y-axis location, participants looked more towards the centre of the field of vision in congested than in free flow ($p<0,01$) or in restricted flow ($p<0,01$). No difference was found for the y-axis gaze location on motorways between free and restricted flow.

On urban road, there was a significant effect of flow density on both the x-axis (congested-free flow $p<0,01$, congested-restricted flow $p<0,01$, free – restricted flow p=<0,01) and on the y-axis location (congested-free flow $p<0,01$, congested-restricted flow $p<0,01$, free – restricted flow $p<0,05$). In the x-axis participants looked more towards the centre of the field of vision in restricted flow, more to the right in free flow and even more to the right in congested flow. In the y-axis participants looked more towards the centre of the field of vision in congested flow, lower than that in free flow and even more lower and closer to the motorcycle front wheel in restricted flow.

The distribution of fixations per road element per road type and traffic density is shown in Table 3. Cohen's k for the annotations by the three observers was 0.96, indicating an excellent interrater agreement (Fleiss 1981). On motorway and in all traffic densities participants fixated more frequently on the right road edge (17.12%), second lane from right (17.01%), third lane from right (9.60%), right side out of road (9.14%) and first lane from right (8.83%), while in urban roads the most frequent fixations were on first lane from right (36.19%), right road edge (13.54%), first oncoming lane (10.40%) and right side out of road (10.29%).

On motorway and in congested flow, the road elements for which participants' fixations accounted for more than 70% of all fixations were: second lane from right (15.47%), third lane from right (14.99%), right road edge (13.16%), lane marking between second and third lane (10.66%), road in general (9.41%) and first lane from right (8.84%). In restricted flow the elements that accounted for more than 70% of fixations were either lane or lane marking: second lane from right (28.66%), first lane from right (12.16%), lane marking between bus lane and first lane (9.69%), lane marking between second and third lane (9.48%), third lane from right (9.48%) and emergency or bus lane (9.07%). In free flow the elements that accounted for 70% of fixations were right road edge (27.62%), second lane from right (13.25%), right side out of road (13.07%), road in general (12.60%) and first lane from right (7.32%).

On urban road and in congested flow the road elements that accounted for more than 70% of fixations were first lane from right (28.75%), road in general (17.92%), right side out of road (15.00%) and right road edge (12.50%). In restricted flow they were first lane from right (59.57%) and lane marking between opposing lanes (14.54%) and in free flow they were first lane from right (24.19%), right road edge (18.95%), first oncoming lane (15.96%) and right side out of road (10.97%).

The Chi2 test revealed no difference in the distribution of fixations per road element between motorway and urban road or between traffic flow density.

Table 3

Distribution of fixations per road element

	Motorway			Urban road		
	Congested flow	Free flow	Restricted flow	Congested flow	Free flow	Restricted flow
Right side, out of road	5.28%	13.07%	8.66%	15.00%	10.97%	5.32%
Right road edge	13.16%	27.62%	2.27%	12.50%	18.95%	6.74%
Emergency or bus lane	0.29%	1.95%	9.07%	0.00%	0.00%	0.00%
Lane marking between bus lane and first lane	5,76%	2,41%	9,69%	0.00%	0.00%	0.00%
First lane from right	8.84%	7.32%	12.16%	28.75%	24.19%	59.57%
Lane marking between opposing lanes	0.00%	0.00%	0.00%	5.83%	9.98%	14.54%
Lane marking between first and second lane	5.28%	2.59%	2.68%	0.00%	0.00%	0.00%
Second lane from right	15.47%	13.25%	28.66%	0.00%	0.00%	0.00%
Lane marking between second and third lane	10.66%	3.80%	9.48%	0.00%	0.00%	0.00%
Third lane from right	14.99%	6.86%	9.48%	0.00%	0.00%	0.00%
Fourth lane from right	0.10%	0.09%	0.00%	0.00%	0.00%	0.00%
Central road barrier	8.26%	1.95%	0.00%	0.00%	1.00%	0.00%
First oncoming lane	0.00%	0.00%	0.00%	5.42%	15.96%	6.74%
Second oncoming lane	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
Road (general)	9.41%	12.60%	3.30%	17.92%	10.47%	0.00%
Left road edge	2.11%	4.91%	2.68%	2.08%	4.24%	2.13%
Left side, out of road	0.29%	1.58%	1.86%	7.08%	3.49%	4.96%

1886 of the fixations were annotated as fixations to specific objects. The distribution of fixated objects per road type and traffic flow density are shown in Table 4. Cohen's k was 0.94, indicating an excellent interrater agreement (Fleiss 1981). Although the Chi2 test revealed no difference in the distribution of fixations per object between road type and between traffic flow density, both on motorway and on urban road the moving vehicles accounted for the majority of fixated objects in congested flow (79.17% motorway, 61.03% urban road) and restricted flow (73.72% motorway, 79.11% urban road) and for the most frequently fixated objects in free flow (48.88% motorway, 46.82% urban road). The second and third most frequently fixated objects in free flow were traffic lights / traffic signs (25.31%) and pedestrians (10.17%) on motorway and pedestrians (17.56%) and road anomalies (16.59%) on urban road. As regards the fixated moving vehicles, on motorways participants fixated equally often on motorcycles and passenger cars in congested flow, while in restricted and free flow they fixated more often on passenger cars than on motorcycles. On urban road they fixated more often on passenger cars in all traffic densities. Considering the fixations on passenger cars, in several cases the exact point of fixation could be clearly determined. The three most often fixated points were the contour of the car ahead (i.e. fixating at the edge of the car ahead and to a point where he can get information both for the car itself as well as for farther ahead on the road), the brake lights and the driver's mirrors.

Table 4

Distribution of fixations per specific object

	Motorway			Urban road		
	Congested flow	Restricted flow	Free flow	Congested flow	Restricted flow	Free flow
Moving vehicle	79.17%	73.72%	48.88%	61.03%	79.11%	46.82%
of which						
Passenger car in general	*14.93%*	*37.23%*	*19.35%*	*16.18%*	*38.67%*	*23.41%*
Passenger car ahead contour	*16.95%*	*17.88%*	*7.94%*	*16.91%*	*30.22%*	*1.95%*
Passenger car mirror	*7.93%*	*3.65%*	*0.00%*	*1.47%*	*0.89%*	*1.95%*
Passenger car brake	*8.40%*	*5.84%*	*5.96%*	*4.41%*	*2.22%*	*3.41%*

lights						
Passenger car window	*0.47%*	*0.36%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Passenger car roof	*0.47%*	*0.00%*	*0.00%*	*13.24%*	*0.00%*	*0.00%*
Moto	*30.02%*	*8.76%*	*15.63%*	*8.82%*	*2.22%*	*5.37%*
Oncoming passenger car	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*2.22%*	*10.73%*
Oncoming moto	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*2.67%*	*0.00%*
Passenger car parked or stopped	1.24%	0.73%	4.22%	11.76%	2.67%	9.27%
Moto parked	0.47%	0.00%	0.00%	0.74%	0.89%	2.44%
Other (bikes, curb)	0.31%	0.36%	0.00%	0.00%	0.00%	0.00%
Bus or bus stop	4.67%	8.03%	5.71%	0.00%	0.89%	0.49%
Traffic signs or traffic light	10.42%	9.49%	25.31%	4.41%	0.00%	2.44%
Road anomaly	1.56%	4.38%	3.23%	4.41%	4.89%	16.59%
Other (entrance, kiosk, protrusion, rubbish bin, pilar, super market cart, tree)	0.62%	0.73%	2.48%	11.03%	1.78%	4.39%
Pedestrian	1.56%	2.55%	10.17%	6.62%	9.78%	17.56%

Evaluation and Conclusions

Although this paper presents the preliminary analysis of data collected from three riders, the findings are valuable and indicate some clear differences in the visual scanning behavior of motorcycles riders in different traffic conditions.

The road type had a significant effect on mean duration of fixations, which were found to be higher on urban roads than on motorways for all traffic densities. This is in accordance to Chapman and Underwood (1998) who report that drivers' mean fixation durations tend to be longer in urban than in rural roads. A possible reason for this could be the lower riding speed on urban roads, which allows the riders to focus for longer time on a specific object while on motorway due to the higher riding speed they have less time available to gather the required visual information from each fixated object for planning their next actions.

Riding in case of restricted flow seems to be more demanding for the riders, since the mean duration of fixations was higher in restricted flow than in free or congested flow on motorway and than in free flow on urban road. This may be because in restricted flow the driving task is more complex and drivers have to handle issues at close proximity, as the riders have to consider the predicted trajectories of other vehicles apart from the existence of pedestrians and the monitoring of traffic signs and lights. On the contrary, in free flow riders do not have to closely monitor other vehicles and issues to be handled are more distant, while in congested flow riders may consider the jammed vehicles as stopped and again they do not focus so much on them.

The analysis also revealed differences in the riders' fixation locations between motorway and urban road. This difference was very clear in the y-axis, where for all flow densities participants looked more towards the center of the field of view on urban road and lower, closer to the front wheel of the motorcycle on motorway. This may be because on the urban road the riders search for oncoming vehicles and pedestrians, while on motorway they focus more on the road surface due to the higher speed. Some significant differences were also found for the x-axis, riders looked more towards the center of the visual field in congested flow on motorway and in restricted flow on urban road. Our finding that the road type has an effect on the mean fixation location are in agreement to Hosking et al (2010), who reported a significant difference between mean fixations locations among residential and rural scenarios in the horizontal plane but not on the vertical plane.

On motorway, the flow density did not have an effect on the gaze location on the x-axis, while on the y-axis participants looked more towards the centre of the field of vision in congested than in free or restricted flow. On urban roads a significant effect of flow density was found for both axes. In the x-axis participants looked more centrally in restricted, more to the right in free and even more to the right in congested flow. This may be because in congested flow participants focus on the risks coming from their right, for example cars in traffic jam that may suddenly steer to the left in front of the motorcycle, pedestrians, cars approaching from right junctions. In the y-axis participants looked more towards the centre of the visual field in congested flow, lower in free flow and even more lower and closer to the motorcycle front wheel in restricted flow. This may be due to the riders' monitoring for road anomalies on the road surface as speed increases on urban road.

On motorway participants fixated more frequently on the road edge and objects outside the road in free flow than in congested or restricted flow. On urban road in free flow, to a greater extent, and in congested flow, to a smaller extent, one notes a shift of fixations to elements outside the road, while in restricted flow fixations are more frequently targeted to elements on the road. Again this may signify that the driving in restricted flow is more demanding for the riders who has to focus extensively on activities taking place on the main road, while in congested and even more in free flow riders may shift focus to points of interest outside the main road. As a general remark, it seems that in free flow the riders' perception resources may be more abundant, thus leaving attentional resources for predictions of possible issues further ahead.

As expected, on both road types moving vehicles are the most frequently fixated objects in all traffic densities. In free flow, a shift of fixations to other objects was noted, namely to pedestrians, traffic lights / signs and road anomalies, and this can be explained since in this case there are no other vehicles in close proximity to the motorcycle. In case of congested flow on motorways riders fixated equally often on motorcycles and passenger cars. This may be because in this case the motorcycle riders shift their focus from the jammed vehicles, who pose no longer a risk, to the moving motorcycles ahead of them, which they consider as "pathfinders" inside the dense car grid.

These preliminary findings shed some light in the visual search patterns of experienced motorcycle riders in real traffic conditions. The results indicate which objects in the traffic environment the experienced motorcycle riders monitor so as to acquire the information required to plan their next actions. The results may be used to promote infrastructure measures which would enhance the visibility of objects on which riders most frequently fixate, for example a better signaling of road anomalies such as shafts may assist riders to identify them more easily and shift their focus on other possible risks. The results can be also used to design support systems, for example systems for automatic recognition of objects of interest for riders and adequate riders' information, so as to enhance riders' situation awareness and thus safety. Future research with larger samples would allow to verify the findings presented in this paper and even to identify possible inter-personal differences on riders' visual scanning strategies. Future research with inexperienced riders in real traffic conditions may assist to understand if and how their visual scanning strategies differ from those of experienced riders and possibly identify adequate training schemes for better hazard recognition.

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