WHERE DID THE CAR COME FROM? – ATTENTION ALLOCATION AT INTERSECTIONS

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ABSTRACT: Accident analyses have shown that about 36 % of all severe accidents happen at intersections, see [1]. It may be that the driver allocates his attention primarily to certain areas of the intersection, neglecting others. In order to examine this hypothesis, a driving simulator study was conducted where traffic density (low and high) was varied in two intersections with either one or two areas of interest (AOIs). Gaze behaviour and the reaction to two critical incidents were examined. 40 subjects (20 novice and 20 experienced drivers) participated in the study. Results of the subjective data show that both traffic density and increasing number of AOIs have a significant effect on the perceived complexity of the intersection. However, the analysis of simulator accidents shows that attention allocation is more important than the complexity. The results of the study will contribute to a better understanding of the role of the driver's attention in the causation of intersection accidents.

1 INTRODUCTION

Driving is a dynamic and complex task and successfully driving in traffic requires a large amount of visual and mental resources [2]. Driving at intersections is thereby one of the more complex tasks due to the high density of visual stimuli. Safe driving in these situations requires the correct detection, identification, and assessment of the visual stimuli by the driver. In a German accident study in 2006 [1], about 36 % of all severe accidents (n= 992) happened at intersections. In most cases, drivers failed to yield to other traffic participants with right of way. When looking at the reasons for this driver error, most drivers reported that they just did not notice the other traffic participant. An in-depth study of bicycle-car accidents [3] confirmed these results and has shown that attention allocation strategies may be important. For example, when a driver turns right and has to yield to cars from the left hand side, he focuses his attention mainly to the road at his left side. If at this point of time a cyclist comes from the right hand side and crosses the road (which he is allowed in Sweden where the in-depth study [3] was conducted), the driver will not notice him with some certain probability. The accident analysis [3] has also shown that this example can be transferred to other situations. Drivers adapt their attention allocation strategy at an intersection to cover the areas where other cars with right of way can come from. With the right turn situation of the example, this results in drivers focusing their attention mainly to one area of the intersection (static attention allocation). In other situations, e.g. a left turn, the drivers' attention will be divided to cars coming from the left and right hand side (dynamic attention allocation). This shift or distribution of attention will probably make it even harder to recognize other traffic participants at other locations.

These findings can be explained by Wickens' et al. [4] SEEV (Salience, Effort, Expectancy, and Value) model. This model includes four critical characteristics of environmental events that influence the operator's attention to selectively sample sources of visual information. Fig. 1 demonstrates the four components.

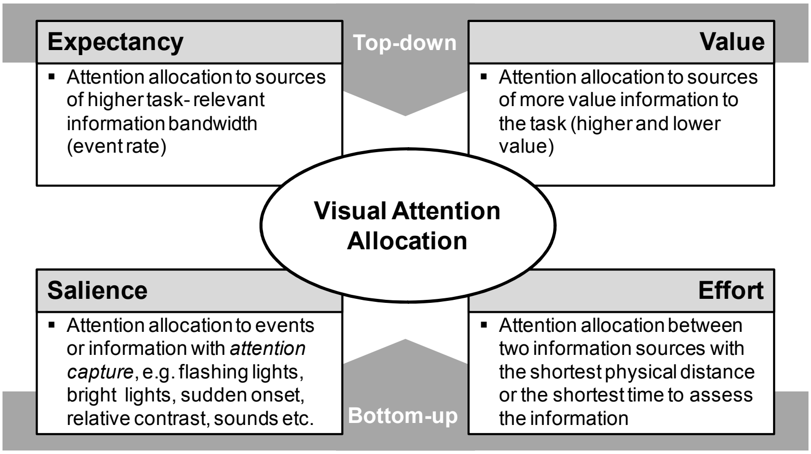

Fig. 1. Four components of the SEEV model

The SEEV model [4] was developed to account for attention allocation strategies when observing multiple displays. In this situation, both bottom-up and top-down processes influence attention allocation. Salience and Effort describe bottom-up processes. Attention is normally captured by salient events in the operator's visual field (attention capture), e.g. bright or flashing lights, contrast as well as sounds. For example, objects with a bright display or an unusual shape of the display are usually looked at more frequently by the operator (high salience). Movements of selective attention require Effort, as people tend to minimize or to avoid long or repeated movements. Thus, a display adjacent to the one where the attention is focused at the moment will be favoured compared to one display further away. For the top-down processes, the Value of the information source is important. People attend more to sources of information that bear relevant information of the present task. For example, if the fuel of an aircraft is running low but the airport is still some miles away, the value of this information will be high and the pilots will frequently watch the fuel gauge. Finally, Expectancy about where and when new task-relevant information will be presented governs attention allocation strategies. The operator's expectations depend on the bandwidth or event rate of the information sources [5, 6, 7]. People will look more often at displays where the information changes more frequently as compared to others where there is hardly any change over time.

Applying the SEEV model [4] to the intersection situation mentioned above, in which the driver wants to turn right, the most important information (Value) arises from his left hand side because other cars may approach from this direction to which the driver has to yield (Expectancy). His attention will be allocated mainly on one area of interest (AOI), looking for a matching gap between the cars from left (static attention allocation). In contrast, when the driver wants to turn left, he has to take both sides of the road into account. He has to shift his attention in turn from the left to the right side (dynamic attention allocation, 2 AOIs). In this situation, the traffic density to the left and right hand side may play a role to influence whether the driver looks more often to the left or to the right side. With regard to the cyclist coming from the right hand side, it is not the usual driving direction and additionally, cyclists appear overall less frequently than cars. Thus, the driver does not expect that the cyclist will come from this direction. This low expectation of the driver will lead to him neglecting this direction and will thus attribute a low value to it. Moreover, because of the driver's head movements when looking for cars from the left hand side, the cyclist will be out of the driver's visual field. As a result, the cyclist and his movement are not salient enough to capture the driver's attention. As demonstrated by this example, the SEEV model [4] is well suited for explaining intersection accidents from an attention-allocation point of view.

For testing the driver's attention allocation in this specific driving situation, a driving simulator study was conducted at the TU Braunschweig. In this study, the main driving task of the participants is turning right at T-intersections. In addition, three environmental factors are varied in the study. Firstly, the T-intersections vary in their number of AOIs: 1 AOI and 2 AOIs. In the condition with only 1 AOI, there are cars coming from the left hand side and driving straight. According to the SEEV model [4] and the accident analysis [3], the driver will direct his attention mainly to these cars with right of way because they are highly task-relevant information for the driver. Thus, his attention allocation is mainly static. In the 2 AOIs condition, in addition to the cars coming from the left hand side there is a zebra crossing with pedestrians on the right side of the intersection. Both areas contain high task-relevant information for the driver, so he will shift his attention between these 2 AOIs (dynamic attention allocation) before turning right. Secondly, the bandwidth of the task-relevant information on the left side of the intersection is varied by using two different levels of traffic density (low and high) of cars coming from left. According to the SEEV model [4], the driver's attention will be more directed to the cars in the high traffic density situation as compared to the lower density situation. As a third factor, driving experience is analysed by testing novice as well as experienced drivers. This was varied because drivers' expectations and thus, their attention allocation at intersections are built up with increasing driving experience. Hence, experienced drivers should have higher expectations where they have to look at than novice drivers. Thus, it could be expected that these two types of drivers differ in their way they acquire expectations as well as they may differ in their search and scan patterns [see 8, 9, 10, 11].

In these different situations, study examines how well the participants recognize another important cue which is situated at a different location at the right side of the intersection. With regard to the SEEV model [4], this should become more difficult when the driver's attention is divided (2 AOIs). More attention resources are necessary due to the shift or distribution of the driver's attention between the left and right side of the intersection as compared to 1 AOI. But it can be also estimated that the shift of the driver's attention to the right road of the intersection and thus, near to the important cue, will support the early recognition of the cue due to the driver's peripheral view. Additionally, the recognition of the important cue should be also more difficult when the traffic density is high. The high bandwidth of traffic or ranges of change will grab the driver's attention more frequently and longer, so the important cue will be seen too late by the driver. With regard to the experienced drivers, it will be expected, that they have higher expectations where to look at the intersections due to their driving experience. This should result in more familiar attention allocation strategies with infrequent important cues more difficult to detect.

2 METHOD

2.1 Participants

A total of 40 subjects, 20 novice (8 men, 12 women) and 20 experienced drivers (18 men, 2 women) participated in the study. Following Fastenmeier [12], the two groups were recruited through three criteria: age, possession of driving license (years) and annual mileage. Table 1 gives an overview about the defined criteria for novice and experienced drivers of this study.

Table 1. Criteria of novice and experienced drivers

	Novice Drivers	**Experienced**
Age (years)	17-24	28-55
Possession of driving license	< 6	> 10
Annual mileage (km/years)	< 9000	> 12000

The novice drivers were on average 21.1 years (SD = 1.4) old. Most of them were psychology students at the TU Braunschweig. They had their driving license for 3.0 years on average (SD = 1.4) and drove on average less than 6000 km in the last year. The experienced drivers ranged in age from 28 to 55 years (M = 41.0 years, SD = 8.9). Average possession of their driving license was 21.7 years (SD = 9.0) and the mean annual mileage was less than 30000 km. Most of the experienced drivers were recruited through an advertisement in local supermarkets and newspapers. All drivers had normal or corrected-to-normal visual acuity and all were extensively simulator trained. The training was conducted on a separate day with duration of approximately 1.5 hours to avoid simulator sickness. All drivers were compensated either five test hours (students at the TU Braunschweig) or 40 Euros for the successful participation at the study.

2.2 Driving Scenario and Test Design

The study was conducted in the static driving simulator of the TU Braunschweig. The participants drove repeatedly through four types of T-intersections. At each intersection they had to turn right. There was a yield sign indicating that they had to give way to cars coming from the left hand side. When the driver approached the intersection, at first there was some oncoming traffic so that the driver got the impression that there will be some traffic at the intersection. When he got nearer, he saw cars coming from the left hand side and driving straight on with a mean velocity of 50 km/h (about 30 mph). Here, different rates of change were introduced by a different traffic density. In the low traffic density situation, there was about 110 m of a distance between these cars. In the high density situation, it was about 70 m. These two levels of traffic density were combined with two types of intersections with different number of

AOIs for the driver. The first type had no other special features so that the driver's attention should be allocated mainly to the left side where the traffic was approaching (1 AOI, static attention allocation). In the second type, a zebra crossing was introduced at the right side of the intersection. Pedestrians were walking and standing around but did not cross the zebra crossing. However, the driver had to watch because this could be the case. In this situation, the driver's attention had to be divided between the left (cars) and the right side (pedestrians) (2 AOIs, dynamic attention allocation). Fig. 2 shows two screenshots of the different AOIs of the two types of intersections.

Fig. 2. Screenshots of the two types of intersections: 1 AOI – only cars from the left hand side (static attention allocation, screen left) and 2 AOIs – cars from the left and pedestrians on the right hand side (dynamic attention allocation, screen right)

These 2 x 2 T-intersections were presented in random order within an urban scenario. This urban scenario consisting of four intersections was driven five times with a short rural road between them. Additionally, the surrounding of the approach to each intersection was designed differently so that the driver got to know each type easily. This was done to facilitate the formation of the driver's expectations for each intersection type.

At the end of the drive an unexpected hazard was presented in the last intersection. After the 20 intersections (four T-intersection types were driving five times), one of the four intersections was presented to each driver again. When the driver entered the intersection and turned right, one of two critical incidents occurred – either a ball bouncing across the road from the right to the left sidewalk or a vehicle parking at the right hand side suddenly started and entered the road. Every participant drove the 20 intersections twice with the two different critical incidents with a short break between the two scenarios. The order of the two critical incidents was balanced across the participants.

In the study, driver behaviour, vehicle data, and gaze behaviour were recorded as well as subjective data. The subjective data according to the four intersection types (without critical incidents) comprise questions, e.g.: How difficult was the intersection? (Complexity); How strenuous was the intersection? (Experienced strain); How much did the intersection require the driver's attention? (Required attention), and How difficult was the decision to approach? (Difficulty of decision). Additionally, an evaluation of the total drive and the last intersection with the critical incidents was obtained. Beside open questions, the participants evaluated the intersections using a 15-point rating scale [13]. For example, according to the question of experienced strain, a scale 1 (very little strenuous) to 15 (very strenuous) was used (see Fig. 3). The rating scale with its five main categories was adapted to the different questions. At the end of the examination each participant was interviewed with regard to the critical incidents and to potential driver errors by the different stages of information processing.

very little strenuous			little strenuous			medium			strenuous			very strenuous		
-	0	+	-	0	+	-	0	+	-	0	+	-	0	+

Fig. 3. 15-point rating scale

3 RESULTS

The results are divided into two main parts: (1) results of the subjective data concerning the four intersection types without critical incidents and (2) results of the driver behaviour at the four intersection types with the two critical incidents concerning the frequency of collisions.

First, in order to describe the influence of traffic density and dynamic of attention allocation (1 AOI = static attention allocation, 2 AOIs = dynamic attention allocation) on the subjective evaluation of the four intersection types a 2 x 2 x 2 design multivariate analysis of variance (MANOVA) with repeated measures was conducted. There is a significant main effect of both traffic density ($F4, 35= 16.934$, $p < .001$) and number of AOIs ($F4, 35= 18.293$, $p < .001$). The interaction between traffic density*number of AOIs is not statistically significant ($F4, 35= 0.959$, $p = .442$). The driving experience as a between-subject factor shows also no significant effect on the subjective evaluation ($F1, 38= 1.049$, $p = .312$). In Fig. 4 the two significant main effects are displayed for the complexity and the attentional demand of the four intersections.

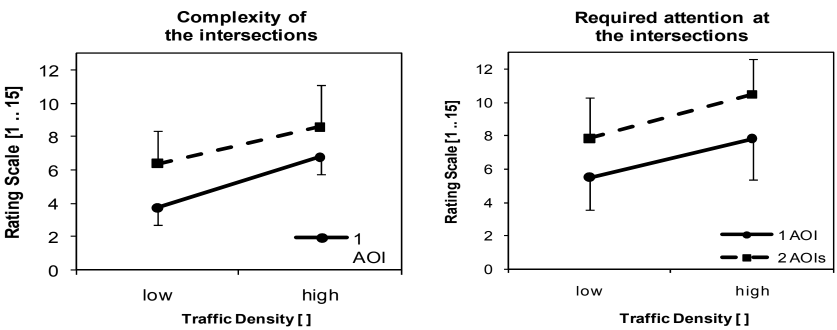

Fig. 4. Mean and standard deviation of the subjective complexity of (left) and required attention at the intersections (right) according to traffic density and number of AOIs

Fig. 4 left shows that the participants evaluate intersections with higher traffic density significantly more difficult ($F_{1, 38}$= 58.034, $p < .001$) than intersections with lower density. Intersections with 1 AOI are rated significantly easier ($F_{1, 38}$= 35.416, $p < .001$) as compared to intersections with 2 AOIs.

With regard to attention required at the intersections similar results are found (Fig. 4 right). The participants evaluate to pay more attention at the intersections with higher traffic density than at the intersections with lower density ($F_{1, 38}$= 45.711, $p < .001$) just as well at the intersections with 2 AOIs as compared to intersections with 1 AOI ($F_{1, 38}$= 61.739, $p < .001$).

Similar result patterns are found for the subjective experienced strain and difficulty of decision. The participants rate the intersections with higher traffic density as being significantly more strenuous ($F_{1, 38}$= 53.595, $p < .001$) than intersections with lower and less strenuous ($F_{1, 38}$= 24.780, $p < .001$) with 1 AOI compared to intersections with 2 AOIs. The difficulty of decision increases with both raising traffic density ($F_{1, 38}$= 56.976, $p < .001$) and increasing number of AOIs ($F_{1, 38}$= 21.238, $p < .001$).

Second, the analysis of the driver behaviour with regard to the frequency of collisions in the two critical incident scenarios shows differences in the chronological order they are driven in the study. Table 2 gives an overview about the collision frequencies in the two critical incident scenarios in regard to the four intersection types and the chronological order of the two scenarios.

Table 2. Frequency of collisions at the four intersection types divided into the order of the two critical incident scenarios

Sequence	Number of AOIs	Traffic Density	Collision in the critical incident scenario: *Vehicle* *No*	*Vehicle* *Yes*	*Ball* *No*	*Ball* *Yes*
In scenario 1	1	High	0	4	1	5
		Low	0	6	0	4
	2	High	1	3	0	6
		Low	2	4	0	4
In scenario 2	1	High	3	3	0	4
		Low	2	2	0	6
	2	High	2	4	1	3
		Low	3	1	5	1
			n= 20		n= 20	

With regard to the suddenly entering vehicle, in the first scenario all participants (n= 10) have a collision at the intersections with 1 AOI. At the intersections with 2 AOIs 3 of the 10 participants perceive the unexpected hazard in time and could stop behind the entering vehicle. In contrast, when the entering vehicle occurs in the second scenario, half of the 20 participants could avoid a collision. The different intersection types are quite similar with the number of collisions. Only with 2 AOIs and low traffic density 3 out of 4 participants manage to avoid a collision which is a little higher than in the other three intersection types.

With regard to the bouncing ball, in the first scenario except of 1 participant all (n= 19) have a collision, independently of the intersection typ. However, when the ball occurs in the second scenario at the intersections with 2 AOIs, 6 of the 10 participants perceive the ball in time and could break. This advantage is particularly shown at intersections with 2 AOIs and low traffic density from the left hand side (5 of the 6 participants).

4 DISCUSSION AND NEXT STEPS

The analysis of the subjective data and the driver behaviour concerning the frequency of collisions at the four intersection types with one of two critical incidents showed two main effects:

First, the analysis of the subjective data indicates that the two difficulty levels of both the traffic density and the dynamic of attention allocation at the T-intersections were successfully varied in the study. This variation showed two additive effects on the subjective evaluation. On the one hand, the participants evaluated the intersections with high traffic density as more difficult and strenuous than the intersections with lower density. On the other hand, the intersections with 2 AOIs (dynamic attention allocation) compared to the intersections with 1 AOI (static attention allocation) were more strenuous and more difficult for the drivers. An interaction between both factors could not be found. The intersections with low traffic density but 2 AOIs and the intersections with high traffic density and 1 AOI were evaluated very similar with regard to their difficulty.

This pattern is not found in the objective data (driver behaviour). First of all, there was a strong time effect. In the second occurrence of a critical event, much more participants managed to avoid a collision than in the first. For the entering vehicle, the percentages were 85 % in the first and 50 % in the second scenarios. For the bouncing ball, we found 95 % and 70 %, respectively.

With regard to the factors varied in the study, there was some indication that drivers managed to avoid accidents better when there were 2 AOIs, in the order vehicle in the first scenario and ball in the second. Looking at the second scenarios, this effect was mainly found when the traffic density was low. This pattern may be explained by the driver's attention allocation strategies: With 1 AOI, the driver's attention is focused to this area at the left hand side. Thus, objects at the right side of the driver (vehicle or ball) are perceived too late. With 2 AOIs, the driver's attention is switch between the left and right side. When the density of traffic coming from the left hand side is high, the driver's attention is biased toward the left in accordance with the SEEV model [4] (Expectancy: attention allocation to sources of high information bandwidth). When the traffic density is low, the driver's attention may be distributed more uniformly towards the left and right side. Thus, objects appearing at the right hand side are perceived earlier by the driver and less accidents happen.

Comparing the subjective and objective data, accidents do not only happen in the most stressful situation (2 AOIs and high traffic density), but also in the least stressful situation examined here (1 AOI and low traffic density). Thus, while high workload may contribute to accidents by causing errors of the driver, low workload situations may also be dangerous because of the driver's attention allocation strategies. Accidents can be best avoided by the drivers at medium workload intersections and with an attention allocation covering different areas where important stimuli may occur.

In order to support this interpretation, vehicle data and gaze behaviour will be examined next. With regard to the vehicle data, speed while approaching the intersections, waiting times at the intersections as well as speed and time gaps while the driver turns right will be analysed. These analyses will be divided into vehicle data at the four intersection types with critical incidents as well as over time. On the one hand, the first analysis will show how drivers react at the four intersection types with an unexpected hazard and will also indicate successfully driver behaviour for avoiding a collision. On the other hand, the analysis over time will show what drivers learn over time and how they may adapt their driving behaviour at intersections. These analyses will provide insight in different driver strategies for avoiding collisions at intersections. With regard to the gaze behaviour, the duration and frequency of glances towards the different AOIs at the intersection will be analysed to examine strategies of the driver's attention allocation.

Finally, the results of the study and the further analyses will contribute to a better understanding of the causation of intersection accidents. The aspects mentioned above can be used to derive requirements for different intersection warning systems – either through specific information for the driver about the current hazard situation and its appropriate reaction, e.g. due to decreasing velocity, or through visual warning signals which attract the driver's attention in the direction of the critical incident. Those could be tested afterwards in the scenarios developed here to demonstrate the increase in traffic safety.

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