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Statistical analysis of "looked-but-failed-to-see" accidents: Highlighting the involvement of two distinct mechanisms

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Abstract

Circumstances where "looked-but-failed-to-see" accidents arise are a particular subject of study. In order to better understand why normal drivers could miss a relevant event signaling danger, more than 500 accidents were analyzed in-depth with regard to driver–environment–goal interactions. Results show four typical situations that imply two distinct mechanisms. When a failure arose at the perceptual stage, drivers actually never saw the danger while they were going straight at a junction or turning left to park their car. When failure arose at the processing stage, there was evidence that drivers saw the danger even when their recall of it was lacking. In fact, drivers saw the danger too late to avoid collision when they were overtaking another road user or looking in a particular direction. These are called "looked-but-failed-to-see-accidents". Accident patterns are discussed according to drivers' goal involvement and local setting to suggest directions for further investigation with a special emphasis on change blindness.
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Keywords: Perceptual failure; Processing failure; Drivers' goal; Environmental setting

1. Introduction

1.1. Background

Road accidents labeled "looked-but-failed-to-see" (e.g. Hills, 1980) constitute a particular subject of study. According to this statement, drivers actually looked in the direction where the other road users were but did not perceive their presence. In the last decade, such accident patterns have been described to characterize car–bicycle collisions (e.g. Summala et al., 1996; Räsänen and Summala, 1998; Langham et al., 1998). A common situation is that the car driver approaches a give-way line at low speed and often stops. Then, the car driver decides to start without realizing that a bicycle is coming up. In such situations, car drivers can look in the direction where cyclists are without perceiving them. However, cyclists are not the only single road users involved in "looked-but-failed-to-see" accidents. As Herslund and Jorgensen (2003) point out, this phenomenon exists in the general accident category "entering traffic against priority traffic" at give-way intersections. Road junctions generate interferences in traffic, which lead to a wide range of characteristic hazards that are difficult to manage for drivers.

So, "looked-but-failed-to-see" accidents provide specific situations, or contexts, where visual perception of relevant information is disrupted. Despite objects' conspicuity and environmental display, specificities of some driver/road combinations lead to behaviors, which do not take specific hazards into account. Numerous physical and psychophysical restrictions on vision could explain the perception failure. Thus, two important factors are put forward; the first factor is the failure in drivers' visual search strategy and/or mental processing (Herslund and Jorgensen, 2003). When drivers have learned a systematic scanning strategy, which is effective in controlling most imminent threats, they failed to detect less frequent and less serious ones (Summala et al., 1996). Moreover, different maneuvers increase drivers' attentional demand and the potential for perception failure (Hancock et al., 1990). The second factor is the layout of the physical environment, which promotes wrong expectations about the situation that might be encountered. For example, a

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great proportion of car–bicycle accidents includes cyclists who come from a direction inconsistent with the normal car traffic flow (Hunter et al., 1995).

Another aspect is the failure to discern the relevant stimulus when a vehicle approaches in the peripheral visual field of the car driver (Rumar, 1990; Lamble et al., 1999). At that point, other road users could be difficult to see according to the eccentricity of oncoming ways. Finally, specific combinations of these factors can complicate the detection of threat in traffic. For example, Räsänen and Summala (1998) show that failure to see a cyclist is highest at an unmarked crossing and at bicycle crossings, where the alignment of a car driver is straight and a cyclist comes from the left or the right onto a major road. Moreover, Langham et al. (2002) show that experienced drivers are less sensitive to a highly conspicuous vehicle (i.e. parked police vehicle) when parked in the direction of travel rather than parked at an angle.

1.2. *"Looked-but-failed-to-see" accident mechanisms*

"Looked-but-failed-to-see" accidents give specific situation–driver–task combinations, which typically result in behavior that does not take certain hazards into account (Summala et al., 1996). Studying these combinations presents two important outcomes; on one hand, it shows some aspects that are likely involved in other particular accidents. More than 50% of all collisions in road traffic can actually be traced back to a missing or delayed hazard perception (Nakayama, 1978). For example, Rumar (1990) suggests that a basic driver error, i.e. late detection, arises from perception failures. Failure to scan a particular class of objects or to look in the appropriate direction leads to deferred perception of relevant information. So, specifications of "looked-but-failed-to-see" accident mechanisms present a greater interest for road safety and accident prevention corresponding to the identification of factors that decrease hazard perception.

On the other hand, failure to perceive very relevant information in the visual field (i.e. a danger) reveals an important aspect of human visual perception. Thus, recent work on the "change blindness" phenomenon (e.g. Rensink et al., 1997; Rensink, 2002; Simons and Rensink, 2005) shows that major change could go unnoticed when it occurs during blink, blank or saccade. Assuming that someone blinks 12–15 times per minute (see Barbato et al., 2000) while making approximately four saccades per second, some authors question how this effect interferes with driving activity. For example, Velichkovsky et al. (2002) show that detection of traffic-relevant insertions in virtual environments was worst when changes occurred during saccades than during blink and blank. Moreover, Shinoda et al. (2001) also demonstrate in virtual environments that the ability to detect stoplight changing during blanks is heavily modulated both by the instructions given to drivers and the local visual context.

Finally, most people firmly believe that they would notice such large changes (Levin, 2002; Levin et al., 2000). This "change blindness blindness" leads to the mistaken belief that unexpected events always draw attention and might help account for "look-but-failed-to-see" accidents (Simons and Rensink, 2005). However, performance is varied according to either the displays (static, dynamic or simulated), the change properties (e.g. insertion, deletion, object-relevance), or the subject's task (e.g. when viewing as a driver or a passenger).

Because perception failure amounts to the problem of when, what, and how information is used to achieve the drivers' goal, specifying mechanisms that lead to perceptual failure in the real world should help to understand event perception in dynamically changing displays. However, "looked-but-failed-to-see" mechanisms remain poorly understood. Most of the studies concern some limited aspects of the phenomenon such as bicycle–car collisions (Summala et al., 1996; Räsänen and Summala, 1998) or accidents involving parked police vehicles (Langham et al., 2002). There is no recent research that covers all the questions of the mechanisms involved. In addition, previous works suffer from limited sources of information. Authors often refer to accidents reported by the police, self-reports or insurance company databases (e.g. Herslund and Jorgensen, 2003) that could possibly obscure some aspects of the situation.

The aim of this article is to better understand why normal a driver could miss a relevant event signaling danger in a large range of driving situations. We investigate in-depth connections between general accident layouts, the driver's current task, and the characteristics of sites in real accident cases. We used a statistical analysis of a detailed database of road accidents. The French National Institute for Transportation and Safety Research (INRETS) has been collecting information about accidents that arise in the region of Salon-de-Provence (population 60,000) and Aix-en-Provence (population 100,000) since 1989. This database is constituted of a systematic listing of the general accident layouts as well as the characteristics of site and those of drivers. Thus, many collection teams, which are connected with the police department and the first aid squads, arrive very quickly on the accident site. To reconstruct the circumstances as accurately as possible, they collect a maximum of objective parameters (weather, geometry, brake marks, point of impact, distance from the driver's home, maneuver at hand, etc.) and subjective parameters (drivers' statement immediately and few days after the accident, travel motivation, driving experience, knowledge of the site, etc.). More than 500 cases of accidents have been collected, involving more than 800 road users. Thanks to this data analysis, we have extracted detailed information from accidents in which drivers claimed they had not seen the danger arise.

2. Accident investigation method

2.1. *Criteria of selection*

Van Elslande and Alberton (1997) have classified the accidents of the database according to the functional failure that can account for the breakdown of driving situations at a given level of the successive processing of information (i.e. at the stage of perception, information processing, decision-making or action). From this prior distinction, the first criterion for selecting accidents as "looked-but-failed-to-see" was the drivers' statement that they did not perceive the danger. Then, we found cases only for the two first stages of information processing: the perceptual stage and the processing stage. For accidents attributable to failures occurring at others stages (decision-making or action), this reason was never pleaded.

Then, we made more detailed selections from these two categories. First, we selected accidents in which visual conditions were excellent (in daylight, with no masking of the visual field). Then, we limited the samples to drivers who must not be distracted at the time of accident (i.e. no passenger, radio off, no mobile phone, etc.). Lastly, we verified that the accident did not occur due to either physical problems rather than attentional perturbation (i.e. no tiredness, no sickness, no consumption of alcohol or drugs).

Thus, we found two samples of accidents. For the accidents due to a failure at a perceptual stage, we found cases were drivers have really no reaction (47 cases). Then, their statement that they did not see the danger was probably true. However, when accidents were attributable to a failure at a processing stage, objective data showed the presence of brake marks or change of trajectory on the accident site. It suggests that the drivers did see the danger even if they think they did not. Actually, drivers had reacted, but too late to avoid the accident (30 cases).

2.2. Statistical analysis

2.2.1. Principal components analysis (PCA)

We used PCA in order to extract specific factors in both accident samples. This kind of analysis is very useful to combine a large number of variables by defining a *join* corresponding to a factor that specifies equivalence, making it possible to link them. Thus, the quantitative contribution of each variable can be hierarchically described, allowing the rapid identification of the explanatory factors.

We analyzed samples separately. We also compared separately variables that characterize the general accident layout, the display of the site and drivers. This method increased the relevance of the interpretation for each field and the strength of the interpretation (i.e. correlations between variables are stronger). Then, the separate analysis allowed the very specifically description of the relationships between variables in each sample.

For the accident layout, we tested 23 variables that characterize the type of site (e.g. urban or rural areas, city center, etc.), the context of manoeuvre which account for the collision (e.g. going ahead through a intersection without priority), the type of collision (head-on, side wipe, etc.), the type of vehicle involved (e.g. car-to-car, car-to-bicycle, etc.), and the general display of the site (e.g. straight road or crossroad, major or minor road, etc.). For the display of the site, we tested 31 variables that characterize the specificities of the site (e.g. category and type of road), the geometry (e.g. winding or straight road, number of lanes, etc.), the surface (e.g. state, dampness, etc.), and road signs (e.g. banning, obligation, etc.). For drivers, we tested 51 variables that characterize the driving experience (e.g. mileage per year, frequency of using a vehicle, etc.), travel (e.g. motivation, distance from home, etc.), the drivers' status (e.g. professional or not), the emergency and accident situation (e.g. task at hand, type of reaction, etc.).

However, the drawback of using PCA is that the resulting relationships between variables and between fields do not correspond necessarily to existing situations. However, the interest of our research is based on the possibility of assuming "how" to consider factors together in the real circumstance. Consequently, we first interpreted the groups of variables in the different fields in order to identify factors, which are specifically involved in the two samples. Secondly, we made an in-depth selection of the accidents according to the variables underlined by the PCA. Then, we found empirical accidents cases, which plausibly illustrated the artificial variable combinations in actual circumstances.

2.2.2. In-depth selection of the accident

Normally, accident cases that correspond to correlated variables can be found by calculating their contribution to the factors (i.e. accidents which strongly contributed to the factors). But here, the separate analysis of the different fields makes impossible such a detailed interpretation. Consequently, we added the specific variables showed by the PCA to the previous criteria to go deeply in the selection of accident. At first, we selected cases in which the totality of variables correlated with the first factor of the different fields was present. Then, we selected the cases in which the totality of variables correlated with the second factor was present, and so on. Finally, we obtained limited cases of concrete accident, which coherently present the same variables as those correlated with the factors, in the same hierarchical order as the factors.

3. Results

3.1. Description of the principal components (PCs)

Generally, the number of PCs that must be considered is determined by adding the rate of variance, which must be greater than 80%. Here, the degrees of freedom and heterogeneity of the variables suppose that 10 PCs might be taken in account to reach this criterion. However, our goal is to extract only the most relevant factors. Then, we examine only the first four PCs, which explained nearly 50% of the each sample.

Tables 1–6 show the linear relationship between the variables and the PCs with the significant value r (i.e. the correlation coefficient) greater than 0.707 or -0.707 (i.e. greater than 50% of the variable is explained by its relationship with the PC). The first PC best explains the whole sample whereas the second PC best explains the correlation of variables with the first factor. Then, the third PC best explains those correlated with the second PC, and so on. When correlation values are both positive and negative, we defined the PC by identifying which factor could cause simultaneously a correlation and an "anti-correlation" between variables. When correlations are either positive or negative, we defined the PC just by identifying which factor could join these variables together. In the same way, we defined a single variable as the PC when it was the only significantly correlated.

Tables 1 and 2 summarize results obtained for the analysis of the accident layout. They show that the main PC is identical for both accident samples. Correlated variables have the familiar

Table 1
Correlation between PCs and accident layout variables involved at perceptual stage.

Component order	1	2	3	4
Percentage of total variance	10	9.15	6.65	5.80
Collide at a crossroad	**−0.920**	−0.016	−0.071	−0.128
X-junction	**−0.889**	−0.359	0.124	−0.128
No made-up	**−0.889**	−0.016	−0.071	−0.152
No “stop” road signs	**−0.889**	−0.023	−0.081	0.054
Collide when going ahead through a crossroad	0.210	**0.846**	−0.099	−0.308
Collide when parking the car	0.620	**−0.793**	−0.042	0.060
Urban area	0.345	**0.783**	0.066	−0.026
Involvement of a two-wheeled vehicle	−0.307	**−0.718**	0.069	−0.417
Car collide with a two-wheeled vehicle	0.136	0.202	**0.806**	0.284
Presence of an obstacle on the road	0.368	−0.078	0.0815	**−0.707**

First line shows component order, i.e. the degree of matter for explains the accident sample. Second line shows its numeric value, i.e. the percentage of total variance explained by the component. Other lines show variables and their correlation coefficient (r) with each component. Bold numbers show significant linear relationship between PC and variable.

pattern of an “unsignaled intersections”, indicating that danger associated with these characteristics constitutes the very specific component that account for the accidents. This is consistent with the typical perturbation generated by “entering traffic against priority traffic” mentioned by Herslund and Jorgensen (2003). It is reinforced by Hamed (1998), who showed that absence of traffic regulation at unsignaled intersections is bound to increase drivers’ exposure to random and risky events. Results show that factors involved at unsignaled intersections have quite different patterns according to the level of information processing failure.

First, at the perceptual stage, there is an opposed correlation between, which assumes that the “specific layout of the conflict” is a predominant feature that leads to the failure to perceive hazard. This suggestion is based on previous demonstration of the special aspects of conflict with two-wheeled vehicles (e.g. Summala et al., 1996) and the specific constraint implied by urban environments (e.g. Underwood et al., 1997; Chapman and Underwood, 1998; Hamed, 1998). The third PC reinforces this assumption with the main correlation of the variable “*car collided with a two-wheeled vehicle*” that underlines the specificity of the conflict encountered. The fourth PC does not have a very straightforward interpretation.

Then, at the processing stage, unsignaled intersection factor is mainly specified by the variables correlated to an overtaking maneuver. As Clarke et al. (1999) pointed out, collisions in these kinds of situations usually arise from a failure to observe an operating indicator on the vehicle ahead, or misinterpret the indicator. From this view, variables correlated to the second PC strongly suggest that a “poor salience of junction” factor could lead to the turning vehicle was unexpected. The third PC is coherent with this interpretation because the correlation of “*head-on collision*” indicates that misperception of the danger arises from an “outcome of overtaking” factor (if collision occurred because a driver made a faulty left turn, then variables such “swipe-side collision” would have been correlated). The fourth PC confirms that accidents typically occur in complex, urban areas with correlated variable related to a “highly built-up areas” factor (which actually contain “*two-wheeled vehicles*”, “*pedestrians*” and “*town-centers*”).

Tables 3 and 4 summarize results obtained for analysis of the display of the site. Again, there is a comparison between the main PC for both samples. Correlation structure strongly suggests that the “urbanization level” is the main explaining factor. This result is not unexpected since more or less urbanized environments induce different aspects of traffic and visual display that lead to typical constraints on driving management (Underwood et al., 1997; Hamed, 1998).

Thus, at the perceptual stage, results assume that the urbanization level is related to a “traffic display” factor. Actually, the second PC opposes variables related to the traffic that might

Table 2
Q3 Correlation between PCs and accident layout variables involved at processing stage

Component order	1	2	3	4
Percentage of total variance	11.34	7.10	6.40	5.70
Collide at a crossroad	**0.707**	0.282	−0.282	−0.546
X-junction	**0.734**	0.150	−0.077	0.329
No made-up	**0.734**	0.524	−0.030	0.322
No “stop” road signs	**0.760**	0.105	0.414	0.061
Collide when overtaking a vehicle which is turning left	0.115	**0.755**	−0.357	0.398
No crossroad frames	0.180	**0.724**	−0.030	−0.322
Urban area	−0.664	−0.194	**−0.769**	−0.324
Head-on collision	0.653	−0.466	**−0.707**	0.079
Involvement of a two-wheeled vehicle	0.0143	−0.231	0.372	**0.748**
Involvement of a pedestrian	0.115	0.398	−0.357	**0.745**
Collide in town-center	0.329	−0.150	−0.077	**0.724**

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Table 3
Correlation between PCs and display of site variables involved at perceptual stage

Component order	1	2	3	4
Percentage of total variance	18.60	10.15	9.40	8
Speed limitation at 90 Km/h	**0.811**	−0.201	0.400	0.074
Speed limitation at 50 Km/h	**−0.710**	−0.464	0.0904	−0.009
Presence of sidewalks	**−0.812**	0.035	0.249	−0.113
Hard verge	**0.809**	−0.325	−0.302	0.430
Presence of more than one way	−0.081	**0.830**	−0.229	−0.134
Double-carriage way	−0.184	**0.799**	−0.048	−0.000
Difficulty road signs	−0.325	**0.784**	−0.101	0.299
Presence of road markings	0.473	**0.757**	−0.059	−0.189
Presence of central frame	−0.134	**−0.710**	−0.009	0.174
Way without priority	−0.134	**−0.710**	−0.009	0.174
No verge	0.049	−0.329	**−0.765**	−0.552
Verges unfit for vehicle	0.049	−0.329	**−0.765**	−0.552
Road without priority	0.277	0.268	−0.041	**0.708**
Presence of urban made-up	0.014	0.166	−0.313	**0.708**

be encountered (e.g. traffic on "*double-carriageways*" or in the presence of a "*difficulty road sign*") against variables related to the traffic function (e.g. regulation according to the "*presence of a central frame*" or a "*lane without priority*"). In addition, this environmental factor is consistent with the "specific layout of the conflict" which we obtained with the analysis of accidents layout. The third PC suggests that traffic display is specifically structured by a "clear limitation of the road" factor (i.e. the impossibility to maneuver outside the road). Lastly, the fourth PC assumes that such limitations are bound up with a "subcategory of the urban road" factor.

At the processing stage, the second PC contrasts variables that are consistent with the "poor salience of the junction" factor showed with the analysis of accident layout. Thus, we propose that a "presence/absence of a central frame" factor is a salient indication of the presence of a crossroad. The third PC also supports this assumption, with the special correlation of "*large secondary road*", which is actually without priority but makes it possible to overtake other vehicles. The fourth PC reinforces this suggestion because variables can be related to a "rectilinear" factor, which is obviously important in the decision to overtake.

Finally, Tables 5 and 6 summarize results obtained for analysis of drivers' characteristics. Data sets are more heterogeneous,

Table 4
Correlation between PCs and display of site variables involved at processing stage.

Component order	1	2	3	4
Percentage of total variance	14.80	11.19	8.90	7.60
Speed limitation at 90 Km/h	**0.713**	0.438	−0.099	−0.211
Speed limitation at 50 Km/h	**−0.846**	0.148	−0.002	0.043
Presence of sidewalks	**−0.730**	−0.279	0.074	0.146
Hard verge	**0.730**	−0.187	0.097	0.493
Collide at a crossroad	0.313	**0.707**	0.104	0.361
Presence of central frame	0.035	**−0.707**	0.175	0.175
Large secondary road	−0.109	0.366	**−0.742**	0.128
Winding road	0.591	−0.440	0.032	**−0.840**
Secondary road	−0.193	0.298	−0.129	**0.730**
Grass verge	0.367	−0.390	0.011	**−0.739**

Table 5
Correlation between PCs and driver variables involved at perceptual stage

Component number	1	2
Percentage of total variation	14	9.95
Rarely driving farther than 50 Km from home	**−0.921**	−0.145
Rarely driving along a motorway	**−0.921**	−0.145
Collide between 9 and 30 Km from home	**−0.921**	−0.145
Driving license obtained since more than 10 years	**−0.723**	−0.019
No speed violation	**−0.707**	−0.273
Frequently driving less than 50 Km from home	0.145	**0.921**
Frequently driving in urban areas	0.148	**0.707**

then significant correlations were only found for the first two factors. Results suggest that drivers' "knowledge about driving activity" is the best explanation for failure at the perceptual stage. The second PC assumes that such knowledge is linked to a "driving habits" factor.

At the processing stage, the main PC indicates that accidents arose "at an unknown place". Thus, the second PC indicates that the "motivation of the route" could be attributed to the reason for driving in an unknown place rather than the professional status of drivers (variables related to taxis, delivery man, etc., have no significant correlation). Finally, the fourth PC does not have a very straightforward interpretation.

3.2. *Illustration of the combination of variables in real situations*

To determine the accident cases which are the most likely to give a comprehensive view of involved factors, we used the 43 contributory variables given by the PCA as additional criteria to make a deep selection in both samples. First, we selected the cases in which all of variables correlated with the first factor of the different fields were present. For example, in the sample of accidents caused by a failure at processing stage, we selected cases which present simultaneously the variables "collide at a crossroad X-junction", "no made-up", "no "stop" road signs", "speed limitation at 90 Km/h" and "hard verge" or "speed limitation at 50 Km/h" and "presence of sidewalks", and "collide at an unknown place". In the same way, we selected again cases with the variables correlated to the second, third, and fourth factors of the different fields. Then, we found four stereotypical situations that present most of the correlated variables in the same hierarchical order.

Firstly, two situations were found for accidents caused by a failure at perceptual stage. On one hand, eight cases (occurring in four different places) showed that drivers without priority

Table 6
Correlation between PCs and driver variables involved at processing stage

Component number	1	2
Percentage of total variation	13.20	9.90
Collide at an unknown place	**−0.921**	−0.088
Route link with professional activity	0.032	**0.706**
No speed violation	0.176	**−0.708**
No maneuver violation	0.176	**−0.708**

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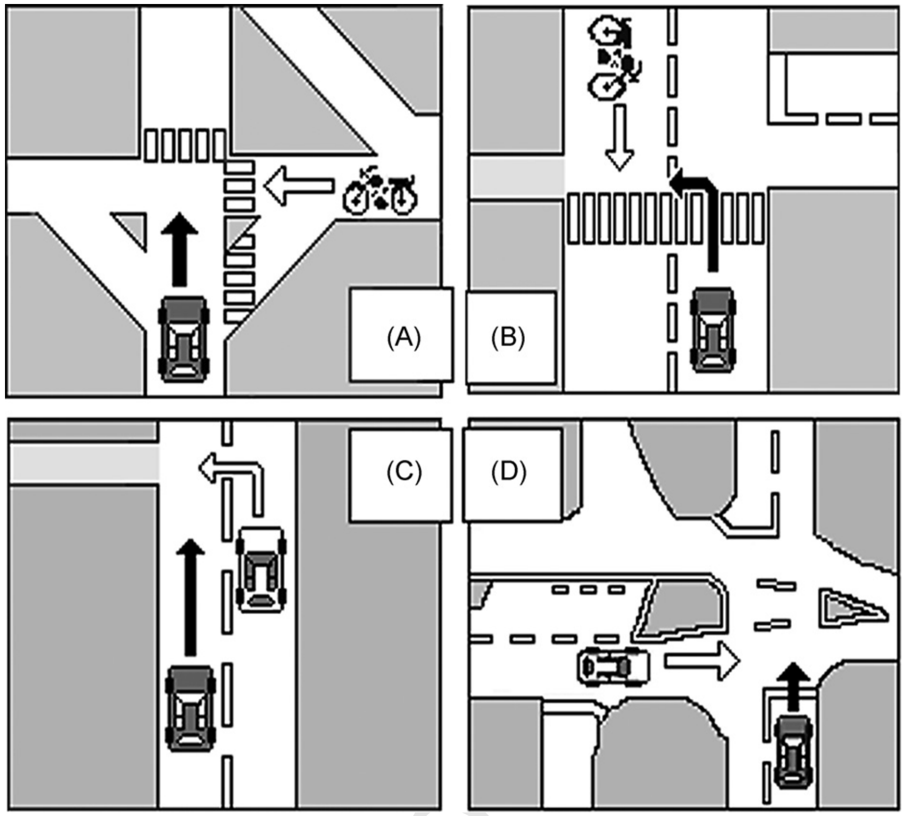

Fig. 1. Typical situations of "looked-but-failed-to-see". Collision course is shown by black ("faulty" car) and white ("right" road user) arrows. "A" shows a example of situation where drivers collide with a two-wheeled vehicle while they are going ahead. "B" shows typical situation where drivers collide with a two-wheeled vehicle while they are turning left. "C" shows typical situation where drivers collide with an overtaken vehicle, which is turning left. "D" shows typical situation where drivers collision with another road user while they are seeking a direction.

systematically slow down and look for an oncoming vehicle while they are driving through a complex crossroads in urban areas or crossing a central frame on major roads in rural areas (Fig. 1A). Thus, they started and collided with a two-wheeled vehicle coming from either right or left. On the other hand, three cases (occurring in three different places) showed drivers turning left on dual-carriageways to park on the opposite verge. Thus, they collided with a two-wheeled vehicle coming from the front while they are crossing the road. These accidents arose exclusively on straight roads near a junction in urban areas (Fig. 1B). In both cases, drivers collided at a well-known place, which they took daily to going shopping or working for example.

Secondly, two typical situations were found for accidents due to a failure at processing stage. On one hand, five cases (occurring in five different places) showed that drivers collided with a car or a two-wheeled vehicle that was turning left while they were overtaking it (Fig. 1C). These accidents took place on large and straight secondary roads, near an inconspicuous crossroad in urban and suburban areas. In addition, the road user who was overtaken had obviously shown his/her intention to turn left (e.g. activated indicators). On the other hand, 11 cases (occurring in five different places) showed that drivers collided with a pedestrian, a two-wheeled vehicle or another car while they had been seeking a direction. Again, drivers saw other road-users but were totally surprised by their action. These accidents took place at complex crossings in urban and rural areas (Fig. 1D). No specific maneuver was found with ACP because drivers collided as they were going straight, or turning left or right. Lastly, in both cases the drivers collided at a place they did not know well. Their travel was link to a professional activity like meeting, visiting people or going to for recruitment.

4. Interpretation

The description of the principal components and the in-depth selection of accidents provide some interesting interpretations of the mechanisms involved in "looked-but-failed-to-see" accidents. The first and maybe the most important results is that there are two kinds of accidents. Although they correspond to the same criteria, two different mechanisms seem to be involved: either an oncoming vehicle is not perceived and the drivers really see nothing, or it is perceived but not the signs that indicate its intentions. In this later case, drivers see the danger even if they think they not. Here is a crucial point of our investigation: even these two mechanisms are comparable in numerous points, they lead both to "looked-but-failed-to-see" in a distinct way. Then, we found that the two important factors as those put forward in literature to explain this type of accident (i.e. failure in drivers' visual search strategy and the layout of the physical environment, which promotes wrong expectations) can lead to this distinction: the explanatory factors involved at perceptive stage are rather related to the setup of the visual search whereas those implied at the level of the treatment are rather related to the setup of the visual environment.

First, we found the same “failure in visual search” explanatory factors at the perceptual stage as that explaining failure to perceive two-wheeled vehicles in the literature. Actually, failure to detect danger is characterized by a combination between the specific layout of the conflict in unsignaled intersection, the specific traffic display according to the road category, and the drivers’ experience. However, many aspects are different from the literature. For instance, our results show that the accidents involve all “two-wheeled vehicle” types, including bicycles, motorbikes, mopeds, and scooters (none of these specific variables is significantly correlated). Moreover, the “specific layout of conflict” factor shows that the misperception is linked to a maneuver placed in the continuum between “going straight ahead” and “parking the car”. It probably excludes the implication of the “right-hand turn” usually recognized in this type of accidents (see Summala et al., 1997). Furthermore, There is no correlation with the presence of particular road organization (e.g. cycle path). Q2

Consequently, our results do not assume that two-wheeled vehicles come from a direction inconsistent with the rest of the traffic. In regard with the prior description in the literature, our study suggest that drivers failed to see a two-wheeled vehicle mainly because it has atypical properties in comparison with the rest of the traffic; illustrations show that situations are obviously complex when drivers lead to numerous sources of hazard. In such complex traffic conditions, the driver’s attentional demand increases because he/she must control threats at an ambient level (Crundall et al., 1998). Thus, experienced drivers have learned a systematic scanning strategy, which is effective in controlling most imminent threats, but increases the potential failure to detect less frequent and less serious ones (Summala et al., 1996). Now, for a car driver, the consequences of a collision with any two-wheeled vehicles are obviously less damageable than collision with another type of vehicle. In addition, conflict with two-wheeled vehicle shows atypical layout (e.g. movement, position on the road, speed, conspicuity) that is unusual for car drivers. Thus, atypical properties of two-wheeled vehicles are very likely to explain why they fail to draw attention in typical circumstances than their unexpected incoming into the normal traffic.

Otherwise, we found the same “layout of physical environment” explanatory factors at processing stage, which promotes wrong expectations as described in the literature. Actually, failure to see warning signs about a wide range of road users from a combination between the poor salience of junction in unsignaled intersections, the specific display of the road, and the knowledge of the place. This combination lead to situations where relevant information is not sufficiently available to perform a complex task, whereas the drivers’ visual search strategy is limited to specific goal-dependant objects. In fact, the outcome of overtaking depends on whether the overtaking driver successfully carries out the appropriate checks and assessments before pulling out to begin the maneuver (Clarke et al., 1999). When environmental signs of the overtaken vehicle’s turning are not conspicuous, the overtaking driver fails to look at the appropriate indication, such as an operating indicator. This interpretation is reinforced by the illustration resulting from the deep selection into this accident sample (see Fig. 1D). Actually, a driver who is looking for a direction must find the relevant information as to which way to go before entering into a road. If this information does not “pop out”, then the increase in the driver’s attention toward searching for this special information decreases perception of relevant information about other road users.

5. Conclusion

We found that knowledge of the driving activity and learned scanning strategies lead to perceptual failures, whereas knowledge of the site and indication availability lead to processing failure. It follows that perception failure is induced by the increasing number of dangers that might be expected, whereas processing failure is induced by difficulty in selecting relevant information for steering. Finally, in both cases, failure arises because another road user is not perceived as a potential hazard. Thus, we suggest that the intrinsic properties of two-wheeled vehicles do not capture the attention at the first stage of information processing (i.e. perceptual stage), whereas cue availability in the visual environment leads to a wrong understanding at a more integrative stage (i.e. processing stage). So, we suppose that perceptual failure is rather caused by internal factors whereas processing failure is caused by more external factors, which both disorient visual scanning strategies.

In conclusion, we note that accident analysis showed that driver’s goal plays a crucial role in the failure to perceived danger. Actually, if some environmental aspects may differ from one typical situation to another, the drivers’ goal is always the same. We suggest that failure arises because the task at hand, meaning the visual search strategy, is inadequate for the current situation. Such a mechanism is invoked to explain the “change blindness” phenomenon. Large object changes that occur during blink, blank or saccade could go unnoticed if they present a “marginal interest” for the task at hand (Rensink et al., 1997). Thus, “looked-but-failed-to-see” accidents could also arise because hazardous events seem marginal for the current goal. This could explain why failure arises in specific contexts with the occurrence of a specific hazard; the spatiotemporal distribution of gaze implied by the completion of the current maneuver in a given environment could lead to representational gaps. Then, certain event cannot attract attention according to their spatial and temporal configurations. But, as Triesch et al. (2003) point out, it is unclear in how far results obtained in change blindness can be generalized to normal visually guided behavior where subjects do not expect any change. Indeed, in typical change blindness experiments, the subjects are explicitly instructed to look for changes. Thus, they suffer from a lack of studies in the real world. So, “looked-but-failed-to-see” situations might be a very interesting research field in natural settings.

Lastly, we have some indicative results to provide readers with some recommendations about the study of “looked-but-failed-to-see”. Actually, we found different accident patterns

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than those usually described in the literature. We suggest that this difference results from bias due to local characteristics of infrastructures, road networks, typical installations, and road user habits in our accident samples. This demonstrates that accident patterns are very specific and should be generalized with care. For example, the geographic zone where information about accidents was collected provides very few cycle tracks. Thus, our results would not present a specific aspect such as the unexpected oncoming of a bicycle (cf. Hunter et al., 1995), but covers more general aspects of two-wheeled vehicles. In the same way, we found a typical situation that is the most common error made when overtaking, i.e. overtaking a vehicle that is turning left. However, this complex maneuver can fail in a number of different ways. Each sub-type of overtaking accident has its own associated causes and types of driver (Clarke et al., 1998). So, mechanisms that we allocated to this typical situation constituted only a certain aspect of the accidents rather than the major cause. Thus, special attention has to be devoted to sampling accidents according to specific subjects of study.

Finally, this last point brings us to the question of what we really call "looked–but-failed-to-see". Actually, we found situations where another road user is seen, but his/her intention is not perceived. However, car drivers claim that they see nothing. At this stage the meaning of "looked-but-failed-to-see" is re-questioned. Indeed, processing failure shows the drivers' inability to perceive warning signs that are very salient and relevant. According to this view, many levels of failure might be considered, one resulting from a purely perceptual phenomenon, the other resulting from the integrative course of information. Consequently, the strong probability of interactions between these two levels (i.e. between the failure in the driver's visual search strategy and the layout of the physical environment) confirms that the "look-but-failed-to-see" phenomenon may be involved in a wide variety of road accidents.

In summary, "looked-but-failed-to-see" accidents show an aspect of visual representation limits. Typical failure to perceive danger in various road structuring reinforces the idea that these situations underline a robust aspect of human perception. Our study showed that perception failure may be distinguished from processing failure, which implies different mechanisms. We explained the reason but not the occurrence of failure to perceived danger. We finally propose that future research should investigate the possible link between failure to perceive danger and change blindness. Such work could help road designers to find countermeasures to fill in potential representational gaps. They could also help authors to interpret the change blindness phenomenon, because at present these experiments do not take actions following human visual perception sufficiently into account.

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References

Barbato, G., Ficca, G., Muscettola, G., Fichele, M., Beatrice, M., Rinaldi, F., 2000. Diurnal variation in spontaneous eye-blink rate. Psychiatry Res. 93, 145–151.
Clarke, D.D., Ward, P.J., Jones, J., 1998. Overtaking road-accidents: differences in manoeuvre as a function of driver age. Accid. Anal. Prev. 30, 455–467.
Clarke, D.D., Ward, P.J., Jones, J., 1999. Processes and countermeasures in overtaking road accidents. Ergonomics 42, 846–867.
Chapman, P.R., Underwood, G., 1998. Visual search of driving situations: danger and experience. Perception 27, 951–964.
Crundall, D., Underwood, G., Chapman, P., 1998. How much do novice drivers see? The effects of demand on visual search strategies in novice and experienced drivers. In: Underwoods, G. (Ed.), Eye Guidance and Scene Perception. Elsevier, Amsterdam, pp. 395–418.
Hamed, M., 1998. The impact of perceived risk on urban commuters' route choice. Road Transport Res. 7, 46–63.
Hancock, P.A., Wulf, G., Thom, D., Fassnacht, P., 1990. Driver workload during differing driving maneuvers. Accid. Anal. Prev. 22, 281–290.
Hills, B.L., 1980. Vision, visibility and perception in driving. Perception 9, 183–216.
Herslund, M.-B., Jorgensen, N.O., 2003. Looked-but-failed-to-see-errors in traffic. Accid. Anal. Prev. 35, 885–891.
Hunter, W.W., Pein, W.E., Stutts, J.C., 1995. Bicycle–motor vehicle crash types: the early 1990s. Transportation Res. Record 1502, 65–74.
Lamble, D., Laakso, M., Summala, H., 1999. Detection thresholds in car following situations and peripheral vision: implication for positioning visual demanding in-car displays. Ergonomics 42, 807–815.
Langham, M., Hole, G., Land, M., 1998. Looking and failing to see error: the cost of experience? In: School of Cognitive and Computing Sciences. Sussex Center for Neuroscience, University of Sussex, Brighton.
Langham, M., Hole, G., Edwards, J., O'Neil, C., 2002. An analysis of "looked-but-failed-to-see" accident involving parked police vehicle. Ergonomics 45, 167–185.
Levin, D.T., 2002. Change blindness blindness as visual metacognition. J. Conscious. Studies 9, 111–130.
Levin, D.T., Momen, N., Drivdahl, S.B., Simons, D.J., 2000. Change blindness blindness: the metacognitive error of overestimating change-detection ability. Vis. Cogn. 7, 397–412.
Nakayama, Y., 1978. Role of visual perception in driving. IATSS Res. 2, 64–73.
Räsänen, M., Summala, H., 1998. Attention and expectation problems in bicycle–car collisions: an in-depth study. Accid. Anal. Prev. 30, 657–666.
Rensink, R.A., O'Regan, J.K., Clark, J.J., 1997. To see or not to see: the need for attention to perceive changes in scenes. Psychol. Sci. 8, 368–373.
Rensink, R.A., 2002. Change detection. Ann. Rev. Psychol. 53, 245–277.
Rumar, K., 1990. The basic driver error: late detection. Ergonomics 33, 1281–1290.
Shinoda, H., Hayoe, M.M., Shrivastava, A., 2001. Attention in natural environments. Vis. Res. 41, 3535–3546.
Simons, D.J., Rensink, R.A., 2005. Change blindness: past, present, and future. Trends Cogn. Sci. 9, 16–20.
Summala, H., Pasanen, E., Räsänen, M., Sievänen, J., 1996. Bicycle, accidents and drivers' visual search at left and right turns. Accid. Anal. Prev. 28, 147–153.
Triesch, J., Ballard, D.H., Hayhoe, M.M., Sullivan, B.T., 2003. What you see is what you need. J. Vis. 3, 86–94.
Underwood, G., Crundall, D.E., Chapman, P.R., 1997. Visual attention while performing driving-related tasks. In: Grayson, G.B. (Ed.), Behavioural Research in Road Safety, vol. 7. Crowthorne, Berkshire, pp. 60–73.
Van Elslande, P., Alberton, L., 1997. Typical "human error"-producing scenarios in road accidents. Rapport INRETS No. 218.
Velichkovsky, B.M., Dornhöefer, S.M., Kopf, M., Helmert, J., Joos, M., 2002. Change detection and occlusion modes in road-traffic scenarios. Transportation Res. 5, 99–109.

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