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## ► To cite this version:

Aurélie Banet, Thierry Bellet. Accident risks of elderly drivers when turning left at crossroads: an in-depth study based on naturalistic and accident data. 30th Annual Congress of the European Association for Accident Research, Oct 2022, Strasbourg, France. 10 p. hal-04201638

**HAL Id: hal-04201638**

**<https://hal.science/hal-04201638v1>**

Submitted on 11 Sep 2023

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# Accident risks of elderly drivers when turning left at crossroads: an in-depth study based on naturalistic and accident data

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**Abstract** – Elderly drivers are usually experienced and careful drivers. However, facing to the complexity of some traffic situations, they may have difficulties to perceive relevant pieces of information, make their decision and perform the right behaviour, resulting in higher involvement in certain types of accidents. It is typically the case for accidents that occur at intersections. Several studies indicate that elderly drivers are overrepresented in accidents that require turning manoeuvres, especially when Turning Left (TL). To investigate the difficulties experienced by older drivers (65 years old and more) and their accident exposure when they have to TL at a crossroad, two databases of the Gustave Eiffel University were investigated for this study: (1) a Naturalistic Database (NDB), collected among a sample of 76 elderly drivers (mean age of 74.4 years old) having performed a 28km route with an instrumented car (a Total of 2150 km covered and 64 hours of data collected) and (2) a Detailed Study of Accidents database (DSA), containing more than 1200 real cases of accidents occurred in Salon-de-Provence area (from 1992 to 2020). As a first step, a conceptual model to study driving errors and accidents risks during TL is proposed. Then, the exploitation of the 2 databases allowed us to extract 43 driving errors observed at the wheel (i.e., NDB) and 26 real cases of accidents (i.e., DSA) occurred during TL, which were respectively analysed and classified according to this conceptual model. Finally, from the joint-analysis of all these real cases of driving errors and accidents, a more comprehensive understanding of accident risks for elderly drivers during TL is proposed and discussed, according to 3 main categories of errors: related to Perception (38.5 % for DSA and 35% for NDB), to Cognition (42.3 % for DSA and 37% for NDB) or to driving Action (19.2 % for DSA and 28% for NDB).

**Keywords** – elderly drivers; turn left; accidents; risks; driving errors

## I. Introduction

Elderly people are usually experienced and careful drivers with a high concern for respecting the safety rules when driving their car (Langford et al, 2006; Classen et al, 2010). Nevertheless, they represent one of the highest risky groups of drivers for crashes with serious injury and death per number of drivers and per distance travelled (Koppel et al, 2011). This is both related to their greater vulnerability in case of accident (increasing the risk of being killed) and to age-related impairments in their physical, perceptive and cognitive abilities liable to generate driving errors and inadequate behaviours (Li et al, 2003, Suen & Mitchell, 1998, Vrkljan and Miller-Polgar, 2005). For instance, limitation of physical abilities, like neck flexibility, may negatively impact some information searching requiring head movements (to check a blind spot area when changing of lane, for instance). Regarding visual perception, older people have specific difficulties in the simultaneous use of central and peripheral vision, which may increase the risk of accident (Baldwin, 2002). At the cognitive level, the speed of cognitive processing of elderly drivers decreases as cognitive load increases. This could be the result of slowed integration of relevant pieces of information, limited memory and attentional resources as well as a decline in executive functions like action planning, inhibition of irrelevant information, mental flexibility to adapt their behaviours in untypical situations. Moreover, older drivers may have more difficulty for dividing their attention between tasks than other drivers because they have less attentional capacity, and multitasking or complex traffic conditions may be more problematic for them compared to younger drivers (Koppel et al, 2009). Another set of studies also showed age-related impairments on cognitive processes of Situation Awareness (SA, Endsley, 1995). In the frame of car driving activity, SA corresponds to a mental representation of the road environment, as perceived and understood by the driver (Bellet et al, 2009). Bolstad (2001) showed that, due to age-related declines in perceptive and cognitive functions, older drivers' mental models of unfamiliar road environment are less complete than SA formulated by younger experienced drivers. Similar results were also found by Kaber et al (2012) for hazardous situations: age negatively impacts the content and adequacy of SA, especially for complex driving situations with a high attentional demand. Faced to the complexity of certain traffic situations, elderly drivers may have difficulty in perceiving and integrating all the relevant pieces of information for making the right decision, resulting in higher involvement in certain types of accidents, typically for situations requiring complex interaction with other road users (Preusser et al, 1998; Larsen and Kines, 2002; Mayhew et al 2006; Langford and Koppel 2006; Clarke et al, 2010; Koppel et al, 2011; Dukic and Broberg, 2012). This may explain the high risk of accident in elderly drivers observed by many authors in intersection crossing situations (cf. Skyving et al., 2009, Van Elslande, 2003; Mayhew et al, 2006; Clarke et al 2010, Braitman et al., 2011, for syntheses carried out in different countries).

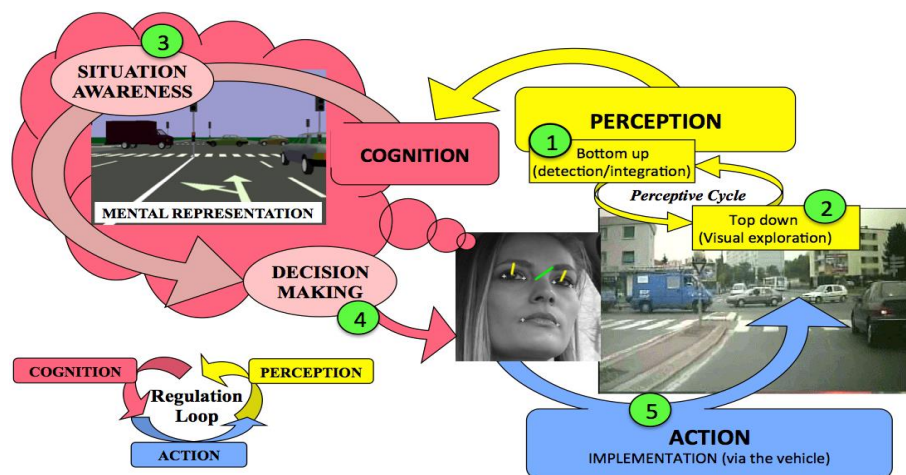
## A. Turning Left at crossroads: a challenging situation for elderly drivers

When considering intersection crossing, turning left situation appears as one of the most difficult tasks for older drivers. A greater proportion of older drivers' crashes occur at intersections, where typically the older driver is turning against oncoming traffic with right-of-way on the main road (Langford and Koppel 2006). Moreover, the more the driver is old, the more this risk is increasing. "For those aged 80 years and over, the percentage of angle collisions, typically involving intersection situations, is more than double that of the youngest groups. The high percentage of angle collisions where the older driver is hit from the side by an oncoming vehicle is another factor that explains why older drivers tend to be the ones injured in their accidents" (Langford and Koppel 2006; p. 312). Similarly, Braitman et al (2007) also reported that failure to yield is found in more than half of the accidents involving older drivers in the US. These crashes occurred more often when drivers were turning left and at stop signs. The authors attributed this fact to misjudgements of the gap available to cross and/or to the time required for performing the turning manoeuvre. They also reported that "look but failed to see" errors were predominant among drivers +80 and older. However, it is not always easy to separated "looked but failed to see" from "failure to properly look". As highlighted by Romoser et al (2013), some of the difficulties of elderly drivers to adequately scan intersections may be also due to a specific attentional deficit to inhibit what has become their prepotent goal of monitoring the vehicle's intended path of travel, thereby causing older drivers to fail to scan hazardous areas outside this intended path of travel.

Difficulties, driving errors and accident risk is at last explained by the complexity of the TL Task as a whole. During the Approaching phase, drivers have firstly to detect the intersection, to indicate their intention to turn left to other road users by activating the left indicator, and then to potentially change of lane for position oneself on the left lane before entering in the crossroads. Another difficulty during this approach phase is to correctly identify the priority rules from the road signs and/or to check the colour of the traffic lights (if existing). Then, for implementing the Crossing phase (in crossroads equipped with traffic lights), the drivers must detect incoming vehicles from the opposite direction to make their decision to cross the intersection versus to stop their car. In case of crossroads without traffic light, the complexity of the task is increased because the driver has also to pay attention to other road users coming from the left and from the right, before deciding to insert in the crossroad. To make their decision to cross, drivers must assess others' vehicles (who have the priority) speed and distance to determine if they can (or not) implement the LT before them. It is probably the most critical decision to be performed when turning left. If the crossing manoeuvre is assessed as "too dangerous" or "not possible" by the drivers, they have thus to identify the right position in the road infrastructure to stop their car, and then to wait until they will detect a safe gap in the flow of the oncoming traffic. Before crossing the opposite lanes, it is also required to check that no pedestrians are walking on the zebra crossing (at the exit intersection) to be sure that the intersection will be fully crossed without stopping the car in the middle of the crossroads, and to avoid disturbing the oncoming traffic. Then, if the way is free, the drivers have to effectively perform the crossing manoeuvre and to leave the intersection by re-checking and/or managing potential conflicts with pedestrians.

## B. A conceptual model to study errors and accidents while Turning Left

Figure 1 provides a synthetic view of the main perceptive and cognitive processes to be implemented to perform a safe TL (adapted from COSMODRIVE theoretical model; Bellet et al, 2009).



**Figure 1:** A classification model to study driving errors and accident risks during tl manoeuvres

The selective dimension of visual information collection is especially important in complex situation like TL, because the driver cannot take in and process all the information available in the road environment. This information is not selected haphazardly, but is the result of a perceptive cycle (Neisser, 1976), whose keystone is the drivers' Situation

Awareness. This mental representation is indeed the true kernel of set of processes ranging from the perception of events to driving behaviours implementation, through intermediate steps of risk assessment and decision-making. However, care is required to avoid taking an over-linear and sequential view of this processing string. Although the detection of an unexpected event may trigger the processing sequence, it is more often the action in progress and the drivers' intentions (i.e. the goal they seek to achieve in the current situation) that direct their visual exploration of the road scene. Consequently, more than a linear sequence of perceptive and cognitive processes, drivers mental activities implemented when driving should be described as a "perception  $\Leftrightarrow$  cognition  $\Leftrightarrow$  action" regulation loop, organized around the driver's SA" (Bellet et al, 2009). In this complex string of perceptive and cognitive processes required to perform a LT manoeuvre, 3 main types of errors may occur (related to the 5 green circles presented on the Figure 1). Regarding **Perception**, we may distinguish "no detection" issue (circle 1) and (circle 2) "inadequate visual exploration or poor search". Regarding **Cognition**, the 2 main risks of errors are related to an erroneous Situation Awareness (circle 3), like a misunderstanding of the priority rules or of other roads users' intention, for instance, and decision making errors (circle 4), by selecting an inappropriate time gap to cross the opposite traffic flow(s). Finally, a last set of potential error may be more related to driving **Actions** implementation (circle 5) for performing the LT manoeuvre with the vehicle (i.e., selecting an acceleration that is not appropriate for the environment such as a driver who accelerates slowly when the gap to the approaching vehicle is short). They may be due to difficulties in piloting the car itself, or be a consequence of to the preceding perceptive and/or cognitive errors.

## II. Method

To support a comprehensive analysis of difficulties experienced by elderly drivers (aged of 65 years old or over) and their accident exposure when they have to perform a turn left at crossroad, two databases of the Eiffel University were investigated for the present study:

- - **A Naturalistic Data Base (NDB)**: collected by the LESCOT laboratory of the Eiffel University among a sample of 76 elderly drivers (70 years old or over) having performed a 28km route with an instrumented car, representing a total of 2150 km covered and 60 hours of recorded data.
- - **A Detailed Study of Accidents (DSA) database**, containing more than 1200 real cases of accidents occurred in the Salon-de-Provence area (from 1990 to 2020), that have been *in situ* collected and in-depth analysed by the LMA laboratory team of the Gustave Eiffel University.

As a first step, the next result section will present successively the driving errors and the real cases of accidents respectively recorded in each one of these two databases. From the one side, the exploitation of the NDB permitted to identify a large set of situations for which drivers experienced a difficulty, whether or not they were aware about their driving errors. In terms of traffic situations, the highest number of difficulties occurred during intersection crossing, more particularly when the drivers had to implement a left-turn manoeuvre at a crossroads. From the other side, twenty-six accidents involving at last 1 elderly driver (from 65 to 90 years old) were extracted from the DSA database. For all these cases, the older driver was assessed as partially or fully responsible of the accident. Results presented in the next section will provide a synthetic analysis of these 26 real cases of accidents, in terms of traffic situation and type of driving errors implemented by the elderly drivers. Then, from a cross analysis of the data available in these two databases, the discussion will provide a combined analysis of human errors and accident risks of elderly drivers when they have to implement a LT manoeuvre at crossroads, in association with the conceptual model presented in Figure 1 (which distinguish driving errors in terms of misperception, inadequate situation awareness, critical decision making, and/or dangerous driving behaviours), in order to support a more comprehensive understanding of accident risks for elderly driver in this particular driving situation.

## III. Results

### A. Naturalistic data: Driving errors of elderly drivers observed in real traffic conditions

The Naturalistic Data Base (NDB) contains a large set of data recorded on an instrumented car equipped with several sensors (like a GPS, video cameras filming the road scene and the driver, front radar, car lane position, and bus CAN data measuring drivers' actions on vehicle controls and the vehicle dynamics) and dual commands. Seventy-six elderly drivers (48 men and 28 women; mean age of 74.4 years old) were invited to drive this instrumented car in real traffic conditions on a 28.3 km route (including urban, highway and rural/peri-urban areas) representing a total of 2150 km covered and 60 hours of data recorded. During the trip, an experimenter was on the backseat and a driving instructor was also present in the car (sitting in the front passenger seat) to monitor the driver and to ensure road safety (from verbal interventions or by control taking of the vehicle if required by the driving conditions). However, the scientific instructions given to the driving instructor was to not intervene or comment any drivers' error during the driving task, except if assessed as highly necessary

for safety or to avoid an accident. The instructor was also in charge of evaluating the driving performance of the participant. Moreover, after the experiment, self-confrontation interview were implemented with the participant, by using the video recorded during the route as support of discussion / self-evaluation.

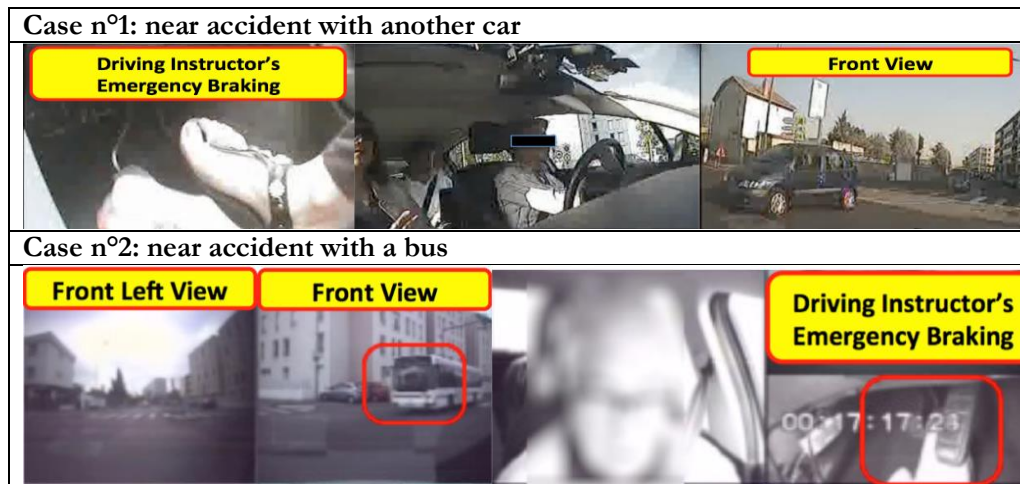
The exploitation of the NDB permitted to identify 265 situations for which our elderly drivers experienced a difficulty, whether or not they were aware about their driving errors. In terms of traffic situations, the main errors occurred during intersection crossing (138 cases, corresponding to 52% of the total number of the driving errors recorded in the NDB), more particularly when they performed a left-turn manoeuvre at an urban crossroads (43 cases, representing 16% of the total number of driving errors and 31% of the errors occurred at intersection). The following Table 1 provide an overview of these 43 driving errors occurred during a LT and their related traffic conditions, according to the classification model presented in Figure 1.

**Table 1:** Classification of driving errors recorded in the NDB

Main origin of the Error	Types of Driving Errors (based-on the classification model presented in Figure 2)	Number of errors (N=43)	Synthetic description of the traffic situations and of the driving errors
Perception (15 cases, 35 %)	No Detection due to a visibility mask (cannot see)	3 cases (7 %)	<b>1 case:</b> no detection of a car in the mirror (i.e., blind spot) when changing of lane to prepare the TL <b>2 cases:</b> mask effect of another vehicle when the drivers are waiting a TL gap in the middle of the crossroads
	Unadequate perceptive exploration of the road environment (doesn't look or pay enough attention)	11 cases (26 %)	<b>4 cases:</b> no mirror checking (and no activation of the indicators), when changing of lane to prepare the TL <b>5 cases:</b> do not look the zebra crossing at the exit of the intersection before implementing the TL, to pay attention if pedestrians are crossing the road. One case of near accident (“emergency braking” of the driving instructor) <b>3 cases</b> of no implementation of a required “re-checking” (i.e. secondary glance) of the opposite traffic before effectively implementing the LT.
	« Looked-but-failed-to-see » (scan visually but doesn't integrate the information)	1 case (2 %)	“Looked but failed to see” error of a pedestrian waiting to cross on the pavement (rudeness gesture of him towards our driver).
Cognition (16 cases, 37 %)	Erroneous Situation Awareness (misunderstanding of the road infrastructure, the priority rules and/or the traffic situation)	6 cases (14 %)	<b>4 cases:</b> Complex interactions with several other road users in the middle of the crossroads. Drivers were totally “lost”, without knowing what they have to observe and to do. Verbal interventions of the driving instructor was required to support them in their understanding of the traffic situation. <b>2 cases:</b> no consideration of the traffic lights (red coloured). 2 verbal injunctions of the driving monitor to stop the car immediately.
	Erroneous decision making due to a misestimation of the available time to cross	7 cases (16 %)	Drivers convinced that they have enough time to cross, although it was absolutely not the case. 5 verbal “order to stop” and 2 “emergency braking” (i.e. near accidents) implemented by the driving instructor to avoid the collision.
	Not able to make the crossing decision by themselves	3 cases (7 %)	Drivers unable to make their TL decision by themselves, disturbing the traffic. 3 Verbal “orders to cross” were provided by the driving instructor.
Action (12 cases, 28 %)	Dangerous stopping position for waiting a safe TL gap	8 cases (19 %)	Drivers stopped their car in a dangerous position in the middle of the crossroads (i.e. a part of their car encroaching on opposite lanes), while waiting to find a safe gap to TL.

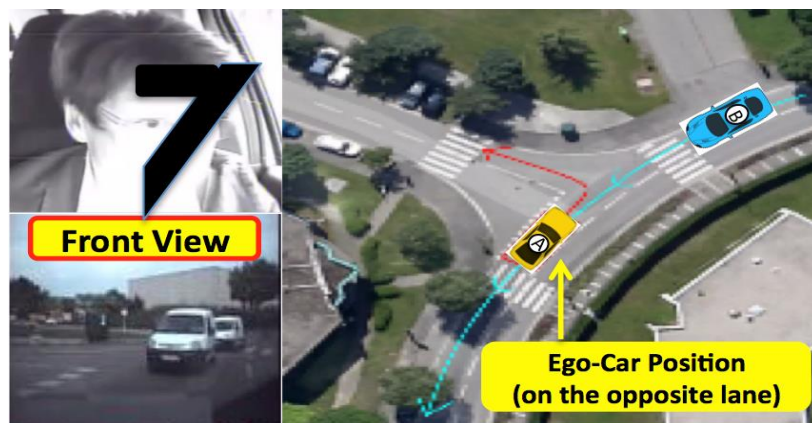
	<b>Lack of control of the TL maneuver or of the vehicle</b>	4 cases (9 %)	<b>2 cases:</b> Too slow crossing manoeuvre (generating flashing lights from the incoming traffic). <b>2 cases:</b> inadequate/dangerous trajectory during the TL manoeuvre (2 verbal interventions of the driving instructor).
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The following figures present 3 examples of elderly drivers' error during a TL at crossroads having generated a critical situation. The first one (Figure 2) presents 2 cases of near accidents due to a misestimation of the available time to cross having generated an emergency braking of the driving instructor to avoid the collision with another car having the priority.



**Figure 2:** Emergency braking of the driving instructor during Left-Turn (NDB)

Regarding driving errors related to erroneous Situation Awareness, the next Figure 3 presents an extreme case of a totally erroneous mental model of the intersection of the participant (due to a progressive involuntary and unaware lane changing/departure during the curve preceding the TL crossroads), who finally stopped her car on the wrong lane (i.e. in front of the opposite traffic). A verbal intervention of the driving instructor was required to convince her to effectively implement the LT manoeuvre.



**Figure 2:** Example of critical stopping position during a Left-Turn (NDB)

## B. Real cases of accident analysis (DSA):

The Detailed Study of Accidents (DSA) programme is managed within the Laboratory of Accident Mechanism Analysis of Eiffel University. For the past 30 years, these studies have consisted mainly of intervening at the scene of accidents in real time with the emergency services in order to gather as much information as possible at the scene to understand the accident mechanism. The accidents analysed are selected primarily according to their level of complexity. In total there are more than 1200 cases referenced in the DSA database, which consists of 319 variables (275 variables minimum when the accident involves a pedestrian). In addition, these data are enriched with video films, photos, external expertise reports, medical reports, interview reports with the actors of the accident, various documentations related to the accident and so on.

In the present study, we analysed 26 cases of accidents involving a person aged between 65 and 90 years in a left-turn situation. From a descriptive point of view, our population was composed of 18 males and 8 females (69.2% males), with an average age of 73 years, and they used their vehicles regularly. None of these drivers tested positive for psychoactive substances, and their slightly impaired and/or corrected hearing and visual abilities played no particular role in the occurrence of the accident. 84.6% of them were already familiar with the accident site, while 15.4% of the drivers had limited or no familiarity with the route (4 out of 26 drivers to be exact). In terms of distractions such as talking to the passenger, listening to the radio, manipulating the controls etc., or a time constraint imposed on the journey, none of these appears to have had any effect in producing the accident. However, all of these 26 drivers caused a traffic accident while performing their TL, and 70% did not perceive any threat when manoeuvring. This explains why 70% of these drivers did not react to the emergency situation. Of these turning drivers, only five of them were able to attempt emergency braking or avoidance (which still resulted in a collision). While the majority of our older drivers were confronted with priority vehicles from both the right (12/26) and the left (13/26), i.e. 96.1% of the accident situations, more than half of them (57.7%) attributed the cause of the accident to the opposing driver (12/26) or to the infrastructure/weather conditions (3/26). As regards the general conditions of the accident, we counted as many accidents in built-up areas as outside them, but mainly during the day (81%) and in clear weather (80.8%) when the traffic is of medium density (57.5% versus light traffic 26.9%; heavy traffic 11.5% and traffic jam 3.8%). The accidents occurred mainly at intersections, with only three cases involving left-turn accidents to access a private road, a car park or to the opposite lane. The configuration of the intersection is also "X" (10 cases out of 26), "T" (12 cases out of 26) and only one "Y". They are governed by "Stop" (38.5%), "Yield" (34.6%), traffic lights (7.7%) and 4 of them have no particular regulation, knowing that 57.5% of these intersections are equipped (painted or hard islands). To complete the overall description of these accident cases, we analysed the data related to vehicles. Given the high number of variables attributed to the "Vehicles" part, we have only kept the most relevant variables considering our object of study. Briefly, all of the vehicles driven by our population were city cars and saloons, in good condition (analysis by the technician) in terms of mechanics, general maintenance, exterior bodywork and the various vehicle controls. Half of our drivers were carrying at least one passenger, usually in the front right-hand seat. The impacts were 88.5% front-to-side, 7.7% front-to-front and 3.8% rear-end, which is consistent with the fact that 88.5% of our accidents occur at intersections. The colour of each vehicle involved is also recorded to determine whether it is in contrast with the road environment (and therefore more easily seen by other drivers). In more than 50% of the accidents, the opposing vehicle had a colour that stood out from the surroundings (e.g. bright red/light/maroon), with similar observations made for the vehicles of older drivers (also more than 50%). After analysing the different cases (two vehicles of contrasting colour with the environment ; priority vehicle of contrasting colour versus non-priority vehicle of non-contrasting colour and vice versa), we affirm that whatever the colour of the vehicle, the "colour/contrast" factor is not relevant in explaining the genesis of the accident. The observation of these factual elements (biographical elements, characteristics of the vehicle, information on the place of the accident and the infrastructure) sheds light on the factual conditions of the accident, but it does not explain why the accident occurred. This second level of analysis presented in following Table 2, focused on the identification of the origin of driving errors, addresses this specific issue.

**Table 2:** Classification of driving errors recorded in the DSA

Main origin of the Error	Types of Driving Errors (based-on the classification model presented in Figure 1)	Number (and %) of accidents (N=26)	Synthetic description of the accident situation and of the driving errors
<b>Perception (10 cases, 38.5 %)</b>	<b>No Detection due to a visibility mask</b> (cannot see)	3 cases (11.5%)	The drivers are bothered by a fixed element (e.g. tree, stopped vehicle) or mobile (e.g. vehicle hiding another) which limits their vision and masks the approaching priority vehicle
	<b>Unadequate perceptive exploration of the road environment</b> (doesn't look or pay enough attention)	4 cases (15.5%)	Drivers explore too briefly the intersection (negligence or inattention) and don't pay a sufficient attention (ex: "I took a glance") before crossing, and they are surprised by the arrival of a priority third-party vehicle.
	<b>« Looked-but-failed-to-see »</b> (scan visually but doesn't integrate the information)	3 cases (11.5%)	the drivers have adequately observed the road scene but have not integrated the occurrence of another road user with priority (typical 'look but failed to see' error; cf. Koustanai et al, 2008)

<b>Cognition</b> (11 cases, 42.3 %)	<b>Erroneous Situation Awareness</b> (misunderstanding of the road infrastructure, the priority rules and/or the traffic situation)	4 cases (15.4%)	<b>3 cases:</b> Drivers have difficulties to understand the road infrastructure / traffic situation (due to their complexities) and decide to cross despite the dangerous conditions, by expecting and adaptation from the other roads user (“he should have avoided me”, “he has to slow down”). <b>1 case:</b> The driver is not familiar with the infrastructure and the road stop marks are partially erased. He thinks (wrongly) that he has priority and crossed the intersection.
	<b>Erroneous decision making due to a misestimation of the available time to cross</b>	5 cases (19.2%)	Drivers underestimate the speed and/or overestimate their distance of approaching vehicles. They think that they have sufficient time to cross and perform the TL before their arrival (“I was convinced that I had time to pass”).
	<b>Don't make the crossing decision by themselves</b> (social pressure or “ripple effect”)	2 cases (7.7 %)	<b>1 case:</b> The driver react to the annoyance of impatient drivers following him and decide to cross the intersection under their social pressure <b>1 case:</b> the driver waits in a flow of vehicles also waiting for a TL. When they cross the intersections, the driver follow them, thinking that it will reduce the risk (possibly feeling of being “protected by the others”).
<b>Action</b> (5 cases, 19.2 %)	<b>Dangerous stopping position for waiting a safe TL gap</b>	4 cases (15.4%)	Drivers are waiting to be able to turn left, but dangerously placed on the road, which sends an erroneous signal to the opposing drivers (suggesting that they are going to cross), or making impossible for them to have a good visibility of the intersection for making a safe decision to cross.
	<b>Lack of control of the TL maneuver or of the vehicle</b>	1 case (3.8%)	The driver enters the intersection but does not accelerate enough to join the flow of traffic. I was hit before completing the TL.

The following figures presents 2 examples of accidents recorded in the DSA-database. The first one is a «Cognitive Error» (i.e. Erroneous Situation Awareness). On a Saturday around 12:00, the 76-year-old driver was driving at a slow speed in a town. Due to a lack of situational awareness, the driver did not understand that he was approaching an intersection and entered the priority lane without detecting the yield sign, thus cutting off another car coming from his left. The frontal collision was inevitable.



**Figure 4:** Arrival to the intersection as seen by the elderly driver (left view) and final position of the vehicles after the accident (right view)

The second example is “Action error”, because of a dangerous stopping position (Figure 5). On a weekday, a motorcyclist was driving on an avenue, she has priority.





**Figure 5:** arrival to the intersection as seen by the elderly driver (left image) and arrival to the intersection as seen by the motorcycle (right image)

The elderly car driver was also driving on this road, but in the opposite direction. He was preparing to make a left turn. He first placed his vehicle across the roadway and then observed the lane assigned to vehicles traveling in the opposite direction. He left one vehicle to pass, then began to cross until he detected the approaching motorcyclist. The elderly driver was a little further down the road and braked. The motorcyclist emergency braked, but lost control and felled off her motorcycle.

#### IV. Discussion

When jointly considering the NDB driving errors presented in Table 1 and the DSA cases of accidents presented in Table 2, both in association with the classification model presented in Figure 1, it is possible to provide a more comprehensive understanding of accident risks for elderly driver in this particular TL driving situation, based on 3 following categories of errors:

##### A. Driving errors related to “Perception” (38.5 % for DSA and 35% for NDB):

- - No detection due to a visibility mask (i.e., “does not detect”; 11.5 % for DSA and 7% for NDB): An object (parked vehicle, road sign, street furniture, other roads users, etc.) masks the visibility of an approaching vehicle (who have priority which is not detected. This type of “masking phenomenon” can pose problems to all drivers, but errors more typical for seniors concerns night driving (0 case in our data, but frequently reported in the literature) and if the effect of mask results from inadequate stopping position (1 DSA case and 4 cases NDB).
- - Inadequate perceptive exploration of the road environment (15.5 % for DSA and 26% for NDB): two possible errors may be at the origin of this risky situation. The first one may be due to fatigue, inattention, mind wandering or worries, distraction, and/or routine driving: the driver initiates the crossing without having looked or paid sufficient attention to other road users having the priority. The second one may be due to an inadequate visual exploration strategy of the road scene, because of the high complexity of the infrastructure or unknown/unfamiliar traffic conditions, high time pressure or a difficulty in sharing visual their attention.
- - Look but failed to see (11.5 % for DSA and 2% for NDB): the driver correctly explores visually the road scene, but does not integrate the information because the other road user does not correspond to the “expected event” (typically: a bicycle or pedestrian, whereas looking for a car). Consequently, the driver engages the TL manoeuvre and enter into conflict (1 case in the NDB with a pedestrian) or collide with the other user (1 DSA case with a bicycle). Braitman et al (2007) reported that these errors were predominant among drivers +80 and older.

##### B. Driving errors related to “Cognition” (42.3 % for DSA and 37% for NDB):

- - Erroneous Situation Awareness (misunderstanding of the road infrastructure, the priority rules and/or the traffic situation; 15.4 % for DSA and 14% for NDB): The drivers are faced with a situation that is too complex for them (complicated or atypical infrastructure, dense traffic, unfamiliar behaviors of other road users), and they are unable to understand it in a comprehensive way (cognitive overload). As a consequence, the priority rules may be misunderstood and/or other road users not adequately considered, or in a too late manner. This is a typical example of difficulties experienced by some elderly drivers when faced to unfamiliar complex situation. Indeed, their driving performance is largely based on their past experience and routine driving, which is fully adapted for familiar driving conditions. However, when the infrastructure or the traffic conditions become atypical, unexpected or too complex, they can no longer cope and adapt themselves because of their limited cognitive resources and their cognitive rigidity. In some cases, they may be overpassed by the situation and totally lost, without knowing what they have to do or where they have to go (e.g. they may stop in the middle of the crossroads).
- - Erroneous decision making due to a misestimation of the available time gap to cross (19.2 % for DSA and 16% for NDB): Drivers adequately observe the road scene, detect the other vehicle and understand that this one has priority, but

they think that they have time to pass (that is not the case). Elderly drivers have more difficulties than youngest to estimate distances and speeds of approaching vehicles.

- - Don't make the decision by themselves (because social pressure or "ripple effect"; (7.7 % for DSA and 7% for NDB): driver experience a pressure of traffic behind (e.g. honks, flashing light) and decide to cross at an unappropriated moment, or reproduce the TL behavior of a followed car. Elderly drivers may have sometimes difficulty to resist to the social pressure, especially when they hesitate for a long time in their decision-making and/or have the feeling of disturbing the others (Van Elslande, 2003). This can push them to make a critical decision to engage the TL manoeuvre despite the risk of the situation.

### C. Driving errors related to "Action" (19.2 % for DSA and 28% for NDB):

- Dangerous stop position to wait for the crossing gap (15.4 % for DSA and 19% for NDB): elderly drivers chosen a dangerous place to stop their car before the TL decision (encroaching on the opposite traffic flow at the entrance or in the middle of the crossroads). Consequently, a collision may occur with other roads users. The eight NDB cases occurred in the middle of a complex infrastructure with multiple interactions in the conflict zone are typical examples of crossroads where the TL situation is difficult to manage in a safe way for elderly drivers.

- Failure in mastering the TL maneuver (like inappropriate trajectory or too slow crossing; (3.8% for DSA and 9% for NDB): in case of complex/unfamiliar situations and complicated interactions with other road user, routine driving largely supporting elderly drivers' behaviors may failed, that can create critical situations (action too slow, too rigid, or not adequately adapted to the traffic conditions).

## V. Conclusion

In this paper, we jointly consider a set of 43 driving errors of elderly drivers during a TL manoeuvre implemented at the wheel of an instrumented car, and 26 real cases of accidents recorded in the LMA accident database. From a common classification framework (Figure1), we identified different types of driving errors liable to concern more specifically this population (summarized in Table1 and Table2). To do that, we focused our analyses about the "main error" at the origin of the difficulties experienced by the drivers. However, it must be noted that all these errors are indeed intimately linked (for instance, a misperception will negatively impact drivers' situation awareness and then their decision making, liable to increase, at last, the risk of a dangerous driving behaviour).

A first limitation of this study is that this research did not compare elderly drivers' errors and accidents with other groups of drivers. Such comparative analyses will be required to identify risks that more specifically concern this population, compared to younger drivers. Another limitation is about the limited number of driving errors and real cases of accidents considered. Further investigations will be required to consolidate these first results. Nevertheless, the conceptual model used in this research is not specific to the Turning Left manoeuvre and has been also applied to other driving situations (e.g. Bellet et al, 2009; Bellet and Banet, 2012). The next objective of our 2 laboratories will be to decline this work by focusing on all intersection crossing situations, which could allow us, on the one hand, to discover other types of driving errors of elderly drivers and, on the other hand, to generalize this classification framework to a greater number of cases of errors and accidents extracted from our two databases.

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