Perceptive and cognitive process in the pedestrian decision-making:
How Do Pedestrians Cross at Intersection ?

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ABSTRACT

In France, about 800 pedestrians are killed and over 17,000 are injured each year. There is a prevalence of these data in urban areas where the traffic is denser and the interaction between drivers and pedestrians is more complex. This can be exemplified by considering the risk taken by a pedestrian situated at a crossroads and willing to cross. This particular situation is indeed highly complex as the loop perception-decision-action is involved.

This paper is aimed at establishing a state of the art on the topic behavioral considerations of pedestrians crossing at crossroads. The purpose of this review is twofold. First, the issues of the behavior of a pedestrian at a crossroads will be defined precisely. We will focus our work on the tactical level described by Michon (1985). This level deals with the choice of actions to operate in the current situational context. Basically, we will ask ourselves what factors influence the decision to cross the street. We will consider psychologically based models to investigate the nature of the processes involved in that cognitively costly task. We will include both perceptual factors (e.g., Langham & Moberly, 2003) and high level processes (e.g., Chu, Guttenplan & Baltes, 2004). Second, we will show how understanding this behavior is fundamental for road users' safety; an experiment will be described that will answer these objectives.

1 - Introduction

Studying walking behaviors in urban settings was the aim of several studies in various disciplines: in Psychology (e.g., Michon & Denis, 2001; Tom & Denis, 2004), in Accidentology (e.g., Carré & Julien, 2000), in Transportation Planning (e.g., Fruin, 1971) as well as in Flow Simulation (e.g.,Yang, Deng, Wang, Li & Wang, 2006). Through these different disciplines, one can observe that these displacements are not always made easy, and neither is their comprehension. In fact, numerous elements of the urban architecture come into play to hinder the progress of pedestrians. Fruin (1971) propose three solutions to this problem, that is, to get better: street lighting, pedestrian circulation and city aesthetics. According to Fruin (1971), except from the urban furniture, the pedestrian improvement program is first based on safety and therefore on conflict reduction between pedestrians and vehicles. Two means are described to attain this goal: a space-based separation (gangway) and a time-based separation (traffic signalization). Notwithstanding, pedestrians' safety is still not attained nowadays. One question is raised by this issue: what lacks to know how pedestrians cross, especially at intersections? Before attempting to answer this question, we will have a quick look at accidentology data.

2 - ACCIDENTOLOGY

Global data on pedestrians

One of the stakes of our work is pedestrians' safety, more precisely when those are crossing streets at a crossroads. Data in accidentology showed that each year in France 800 pedestrians are killed, and 17,000 are injured (Brenac, Nachtergaële & Reigner, 2003). 95% of the bodily accidents involving at least one pedestrian take place in urban settings and make 82% of the pedestrians killed. Nevertheless, the risk for a pedestrian to be killed when s/he has been hit by a car is 3 to 4 times higher outside urban environments. In the US, data showed that in 2005 there were 4,881 pedestrians killed and 64,000 injured in traffic crashes (NHTSA).

Data show furthermore that the most involved populations are those of children under 15 and of older pedestrians (Koepsell et al., 2002; NHTSA). In France, it is in May, October, November and December that these accidents are the most numerous. They happen mostly on Mondays and Thursdays, between 4:00 pm and 7:00 pm. These accidents occur above all during the day, under normal weather. In the US, 43% of the young (under age 16) pedestrian fatalities occurred in crashes between 3:00 pm and 7:00 pm. Most of these fatalities happened in urban areas (74%), in normal weather conditions (89%).

Lastly, 34% in France vs. 20% in the US of the bodily accidents that involve at least one pedestrian happen at an intersection. Though less frequent than on a straight road section, there is a risk of seeing the frequency of these accidents grow. Indeed, a reflexion proposed by Rennesson (2004) to provide displacement safety to pedestrians would be to establish pedestrian crossings at crossroads in order to better regulate traffic flows. If so, crossroads would become new stakes for road safety. We will accordingly concentrate on this case in the next section.

Data on crossroads

The works of Brenac et al. (2003) use a method to elaborate typical pedestrians' accident scenarios. This method consists of three phases:

- case analysis
- grouping together the cases judged similar, that is, elaborating a classification
- explanation of the progress prototype corresponding to these cases

From a sample of 189 detailed cases of accidents, 20 typical scenarios have been extracted. On these 20 scenarios, 2 are related to a crossroads. Thus, in typical scenario #8, the driver turns then hits at the exit of the crossroads a pedestrian who crosses, this one often being not seen. This case stands for 5.8% of the bodily accidents in the 189 cases database.

In typical scenario #10, the driver gets over an orange or red light and hits at the exit of the crossroads a pedestrian who is seen too late. This scenario stands for 1.5% of the bodily accidents.

The data we have just mentioned allow us to establish the relevance of studying road crossing by the pedestrian at the crossroads. For this purpose, our theoretical framework will be Michon's model (1985), set out in what follows.

3 - THEORETICAL FRAMEWORK : MICHON'S MODEL (1985)

Framework of the model

Michon (1985) has a tripartite conception of the driving task. In fact, he supposes three different processing levels:

- the strategic level: it deals with route planning and with the navigation task
- the tactical level: at this level are gathered different actions, such as obstacle avoidance, overtaking, choice of inter-vehicular distance or speed choice.
- the operational level: it is about the execution of the actions that were selected at the tactical level

Van Winsum (1996) showed that these levels were strongly interdependent. Thus, each factor that affects the performance at the operational level results in a behavioral adaptation at the tactical level.

This model can easily be applied to the pedestrian who deals with a displacement task including road crossing at a crossroads. The strategic level would deal with the choice of the route to travel. The tactical level would then be divided in two sublevels: the upper tactical level would deal with the adequate place where to cross (Chu, Guttenplan & Baltes, 2004) whereas the lower tactical level with the choice of the actions that should be realized in the current situational context. Finally, the operational level would correspond to the motor sequence that should be done to cross.

Our position relative to the model

The work we present here is focused on the tactical level. Applied to the pedestrian, the question raised by this level is then the following: *why and thanks to what information a pedestrian make the decision to cross?* This question appears to be all the more important as the pedestrian can be situated in a complex environment, like this is the case at the crossroads. We will deal with this question in the next part.

4 - PSYCHOLOGICAL PROCESSES INVOLVED IN THE ROAD CROSSING TASK AT CROSSROADS

Perceptual processes

Among perceptual processes, *vision* and *audition* are of preponderant importance in the crossing problematic, for the driver as well as for the pedestrian. Indeed, mutual perception of road users is essential as drivers and pedestrians must clearly perceive the movements other people do in order to evaluate what movements can be done. In what follows, we will concentrate on vision. As a matter of fact, Hills (1980) indicates that over 90% of the information input to the motorist is visual. Moreover, the study of Guth, Ashmead, Long, Wall & Ponchilia (2005), conducted on three roundabouts different in size and in traffic flow, aimed at comparing the performance of blind vs. sighted subjects in a road crossing task. More precisely, the task was to judge if the gap between two vehicles was large enough to cross and go to a pedestrian refuge situated midway from the kerb. Blind subjects were 2.5 times less effective in that judgment task, take more time to identify crossable gaps, and were more likely to miss crossable gaps. Studying the behavior of elderly people is also a key point to understand the role of perceptual, cognitive and motor factors in a road crossing task. The deficits in those when ageing reveal their importance, notably this of vision in perceiving and integrating distance and speed information (Oxley, Fildes, Ihsen, Day & Charlton, 1995; Oxley, Ihsen, Fildes, Charlton & Day, 2005). Oxley et al. (1995) indicate that crashes involving the elderly often occur at a crossroads. Once there, they frequently do not see the vehicle that hits them; when they do see the car, they think that the driver saw them and will take some evasive actions.

Langham & Moberly (2003) underline that one reason for which the rate of killed/injured pedestrians is so high is that they are not conspicuous enough. In return, it is also possible that the lack of conspicuity is related to the approaching vehicle. This can be due for example to an excessive speed of the vehicle, to the number of interactions with the vehicles, etc. It is noteworthy that considering conspicuity from the pedestrian's point of view is an issue rarely mentioned in the literature.

It is important to recall that Engel (1971) was the first to define conspicuity as the size of the background area within which a target can be detected during a brief presentation; thus, there is no need of a visual search to be detected. This definition differs from the one of 'visibility' given by Engel: it is the ease of detection when the observer is aware of the localization of the target.

According to Langham & Moberly (2003) and Hills (1980), in the context of driving, the most important factors for visual conspicuity of a target are:

1. The visual size
2. The contrast with the background
3. The ambient light levels
4. The presence of glare
5. The color

To these factors, one should add the *complexity of the background*. Indeed, Paulmier, Brusque, Carta & Nguyen, (2001) showed that complexity influenced the ability to detect a target. In this study, the complexity criterion was the number of rectangles per surface unit. The authors found that the higher the complexity was, the higher the visibility had to be to detect the target. It is noteworthy that in this research the visibility has been operationalized using the VL ratio (for Visibility Level, see CIE 1981a, 1981b) :

$$VL = | \Delta L_{actual} | / \Delta L_{threshold}$$

where L_{actual} is the luminance difference between the target and the background whereas $\Delta L_{threshold}$ is the differential luminance threshold needed to detect a target on homogeneous background with a probability of about 100%.

Finally, three parameters are necessary to compute visibility of pedestrians by drivers when crossing at a crossroads. Let's note that here the term 'visibility' is no more related to photometric concerns, as mentioned above. The first factor to take into account is the speed of the vehicle, or rather its estimation, made by the pedestrian. This corresponds to the moving obstacles defined by Gibson & Crooks (1938) for who clearance lines radiate from the point of potential collision. The estimation of the speed would be difficult *per se* but on the basis of perceptual skills, it can be straightforward. These skills are automated and non conscious processes, which execution is by definition very fast (Rasmussen, 1983).

The second factor considers both perception and reaction times. This perception-reaction time has been recommended to be fixed to 3 s by the TRB (2000). The last factor is the time needed to cross, which can be either observed *in situ* or either inferred from walking speed (supposed constant) and from the distance to cross. Judging gaps adequate to cross is based rather on inter vehicular distances than on speed (Simpson, Johnston & Richardson, 2003). Gap acceptance is widely used as a safety criterion to cross: gaps smaller than the critical gap will be rejected (Yang et al., 2006). Yang et al. (2006) also mentioned the role of interactions among pedestrians: once an appropriate gap has been identified, the first pedestrian to cross will be followed by other pedestrians.

In fine, it appears from the studies mentioned above that conspicuity has an important role when considering road crossing, and that different parameters have to be taken into account to better understand this concept. To conclude, the hypothesis is advanced that it is especially the case at the crossroads where the information from the optic flow is particularly dense (Norman & Bobrow, 1975).

Cognitive processes

Besides the physical or perceptual factors mentioned above, there are some cognitive factors to take into account, notably *attentional factors* that come to determine the frequency of detection. Relative to cognitive conspicuity, Cole & Hughes (1984) thus distinguish between:

- Research conspicuity : ability of a target to be easily localized by visual search
- Attention conspicuity : propensity of targets to attract attention when the observer is not instructed to look for them (see for example the 'cocktail party' effect).

It is generally acknowledged that attention has a property of selectivity; James stressed it as early as 1890 and this notion has then been developed by Gibson & Crooks (1938). Moreover, attention modifies the quality of the cognitive representations on which it operates (James, 1890). It is present in almost all our behaviors (Camus, 2003). In a road crossing task, notably at a crossroads, it is the visuo-spatial attention that will be involved. Posner (1980) showed that two zones should be taken into account when considering visuo-spatial attention:

- a zone that is as illuminated by a beam of rays where information is perceptively emphasized, where the decisions are more efficient and reaction times shorter : it is the attentional benefit.
- a zone that corresponds to peripheral regions which are inhibited, resulting in an attentional cost.

According to Camus (2003), attention is notably necessary to overcome the limitation of our cognitive resources or to integrate independent information. This hypothesis of the integrative role of attention has been tested in visual perception. Simons (2000) and O'Reagan, Deubel, Clark & Rensik (2000) thus put in evidence the change blindness phenomenon, that is, the observer's inability to detect an obvious change in a visual scene when attention is concentrated on something else. In the driving situation, this corresponds to the 'looked but failed to see' error which can cause an accident (Hills, 1980). The work done by Itti & Baldi (2005) shows nevertheless that under certain circumstances, attention can be attracted by surprising events: 72% of the fixations are directed toward these ones.

Attention is also necessary to control the access to *working memory*: Baddeley himself (1997) stated that the central executive is equivalent to an attentional processor. In Baddeley's model, memory is broken down into a storage space called the central executive and two slave systems dedicated to rehearsing and refreshing information: the phonological (or articulatory) loop and the visuo-spatial sketch pad. In a road crossing task that has to be completed by the pedestrian, working memory is systematically solicited. In fact, it is about storing relevant sensory information, essentially visuo-spatial information, while keeping processing new information coming from the various legs of the crossroads; this comes to stress the double simultaneous activity - processing and storage - that is the core property of working memory. We are hence dealing with a pool of processes that are resource-limited (Norman & Bobrow, 1975; Barrouillet, 1996). Given the key role of visuo-spatial information in the crossing activity, the phonological loop would not be involved in this activity. Furthermore, the limited feature of working memory being well established, we can hypothesize that a high mental load will have some consequences on the quality of crossing and subsequently on pedestrian's safety. The visuo-spatial sketch pad has as a function to maintain and to process information that has the format of a mental image (Baddeley, 1997; Barrouillet, 1996), accordingly the notion of mental representation shall now be tackled.

The notion of mental representation is fundamental when taking into account the crossing activity. It is the core notion in the diagnosis model proposed by Hoc & Amalberti (1994). These representations are assisted by automatic processes and general knowledge. They can be represented as mental images that can be mentally transformed or rotated (Denis, 1991). In this case, they have functional and structural similarities with visual perception. More than their format, it is their adaptive and dynamical features that will interest us here, notably the fact that they can modify their content to remain in adequacy with the changes in the environment. There is an evocation or a construction of a (sub)symbolic representation that allow the subject to access immediately to his/her procedural knowledge (Hoc & Amalberti, 1994). In fact, in the situation of street crossing, a main variable is the time variable: the crossing task often occurs under temporal pressure. This is particularly the case at the crossroads where the mental representation of the situation at t0, based on volumes flows and on vehicles speeds at various legs, becomes obsolete at t1.

Lastly, the importance of the notion of *risk taking* should be stressed. Himanen & Kulmala (1988) applied logit models to the analysis of road crossing, from the point of view of the driver as well as from the one of the pedestrian. One of their results showed that if a pedestrian crosses at a pedestrian crossing, the detection probability of the pedestrian by the driver is higher than if s/he crosses elsewhere. This result can be explained notably by the driver's expectations that are higher for the behaviors that are in adequacy with road signaling. Nonetheless, it is often the case that street crossing happens outside the pedestrian crossings. Pedestrians take risks notably when trying to shorten distances (CETUR, 1983) and waiting times: 64 % of the pedestrians stay less than 4 seconds on the sidewalk before starting to cross (de la Sablière, 1988). A report of the CETE in Rouen, France (1982) has besides shown that in order to cross, the pedestrian takes the vehicles as anchors and has the tendency of underevaluating the time necessary to cross. Lastly, data from a Chinese study have shown that 23.3% of pedestrians take an illegal action when crossing streets (Yang et al., 2006). How can one explain these facts? Wilde's (1982, 1984) model of risk homeostasis may give an answer to this question.

In this model, the hypothesis is made that each time a road user (driver or pedestrian) perceives a certain level of risk, s/he compares it with the one s/he wishes to accept. If the two levels of risk differ, the individual will provide an action in order to eliminate this difference. This adjustment action is related to a possible accident rate. Indeed, some dangerous situations, conflicts, dysfunctions causing security troubles (errors) happen. When the sum of these accident rates is made, these adjustment actions will determine the frequency and the seriousness of the accidents. This will be named accident rates and has an influence on the level of perceived risk, though this influence could be lagged.

5 - THE ROAD CROSSING TASK AT CROSSROADS : AN EXAMPLE OF DIAGNOSIS

According to Hoc & Amalberti (1994), the human operator always tries to remain in capacity to act. This conception can easily be applied to the pedestrian at the crossroads. In order to cross, it will be necessary to manage three elements: the resources which are limited, the risks and the costs. A diagnosis of the situation will thus be considered, the criterion for stopping the diagnosis being the decision-making. This decision will be to choose the adequate moment when to cross. Based on the psychological factors that we put in evidence in the previous sections, the construction of a diagnosis remains progressive and depends on different strategies. Thus, Rasmussen (1986) distinguishes between two categories. Topographic strategies are based on the knowledge of normal working of the system; symptomatic strategies rely on the dysfunctions of the system.

In the model proposed by Hoc & Amalberti (1994) on diagnosis, the human operator is by contrast with Rasmussen's model (1983, 1986) capable to process information in parallel.

This is fundamental at the crossroads where the subject has to integrate information coming from multiple sources in order to make the decision of crossing. Moreover, Hoc & Amalberti (1994) propose that the human subject is conceived as an anticipative system and thus not essentially reactive. This last notion is a core one and can be applied to road crossing at crossroads: indeed, we permanently anticipate possible collisions in order to avoid them and to cross safely.

6 - EXPERIMENTAL PROSPECTS

When two tasks are achieved simultaneously, as soon as the cognitive resources are transferred from the first to the second task, the performance in the first task will deteriorate: this is a trade-off phenomenon (Barrouillet, 1996). Based on Baddeley's model of working memory, we will now present an experiment which can be realized in order to explore both the behavior of participants in a road crossing task at a crossroads and the role of working memory in this task.

Method

Participants: 60 young participants will take part in this experiment, this figure being chosen for its statistical power. This sample will be composed preferably of the same number of males and females. Indeed, males are widely known to perform better in spatial tasks.

Materials:

An articulatory suppression task and a spatial tapping task have been chosen after the work of respectively de Beni, Pazzaglia, Gyselinck & Meneghetti (2005) and of Hegarty, Mayer, Kriz & Keehner (2005). These are tasks that are intended to create a dual-task paradigm. There will be two spatial tapping tasks, namely level 1 and level 2, according to their respective difficulty. The simulated road environment will be generated from a simulator. Sounds made by the vehicles will be included.

Hypotheses:

As people rely first on distance to make their decision to cross (Oxley, Lenné & Corben, 2006), the importance of spatial information on road crossing is now well established. The use of a spatial interference task would then deteriorate the performance of participants, all the more as this task involves a high mental load as this is the case for spatial tapping level 2. The articulatory loop would not be involved in the road crossing task, and accordingly the performance of the participants in this group should not differ from the one of the control group.

Results

Below are the dependent variables that shall be considered in this future experiment :

- Walking time : mean walking time between normal and fast paces.
- Decision time : time between the arrival at the kerb and the departure from the kerb.
- Occurrence of head/body movements and location where this happens (at kerb or during road crossing) / where it is directed to, that is:

  -to the near-side traffic
  -to the far-side traffic
  -to another leg of the crossroads
  -ahead
  -to the ground
  -other

- Number of collisions.
- Number of tight fits : defined as the proportion of road crossings in which the vehicle was less than 1.5 s away from colliding with the participant (cf. Simpson et al., 2003).
- Number of gaps before the participant chooses to cross.
- Time spent completing the road crossing task.
- Safety margins = time gap - (mean walking time + decision time); cf. Oxley et al., 2006.

Perspectives

The final aim of this experiment is to allow to improve the pedestrian's behavior models. Indeed, one of these model is to settle perceptive and/or cognitive filters in order to better understand some specific situations, such as the one when a pedestrian is not seen by a vehicle coming from the right or left.

7 - CONCLUSIONS

Making the decision to cross the road at a crossroads is a highly complex task which requires efficient perceptual and cognitive processes. In fact, one has first to detect the vehicle and integrate information from the various legs of the crossroads in order to form a mental representation of the situation. This representation must be frequently updated to stay in adequacy with environmental changes. Accordingly, we hypothesized the importance of the following psychological processes : visual conspicuity, attention, working memory, mental representation and risk taking. We then proposed an experiment which can explore behaviors during road crossing at a crossroads and test the influence of a moderate or high cognitive load on the performance of the subjects. It is noteworthy that this short review of the literature is not intended to be exhaustive. For instance, other visual factors can be put in evidence such as speed perception. Further, other perceptual factors may come into play, such as auditory ones which certainly help the pedestrian to locate the sounds of coming vehicles. These factors will be considered in a future review.

8 - REFERENCES

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