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Red light violations by adult pedestrians and other safety-related behaviors at signalized crosswalks

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ABSTRACT

To study human factors linked to red light violations, and more generally to safety-related behaviors at signalized crosswalks, the present study combines the collection of observational data with questionnaires answered by 422 French adult pedestrians. Thirteen observed behavioral indicators were extracted (12 before and while crossing, and red light violation), and the roles of several demographical, contextual and mobility-associated variables were examined. The results of the stepwise logistic regression analyses carried out on each of the 12 behavioral indicators observed before and while crossing revealed that gender had no major impact, but age did, with more cautious behaviors as pedestrians were older. The three contextual variables (group size, parked vehicles, and traffic density), as four mobility-associated variables (driving and walking experiences, self-reported crossing difficulties and falls in the street) were also found to be important factors in safety-related crossing behaviors. A wider logistic regression analysis, made specifically on red light violations with all behavioral indicators observed before and while crossings and the several demographical, contextual and mobility-associated variables put together, showed that red light violations were mostly affected by current situational factors (group size, parked vehicles) and particularly associated with some behavioral patterns (looking toward the traffic, the ground, the light, running and crossing diagonally). The overall results encourage the development of safer pedestrian infrastructures and engineering countermeasures.

Key-words: pedestrians; signalized crosswalk; observation; violation; safety

1. Introduction

Among road users, pedestrians are the most vulnerable to traffic injury. It has become highly challenging for pedestrians, especially older ones, to cope with the complex, sometimes hostile, traffic conditions that characterize today's cities and towns (OECD, 2011). The Organization for Economic Co-operation and Development (OECD) reported in 2011 that over 20,000 pedestrian fatalities occur annually in its member countries, ranging from 8 to 37% of all road fatalities. Worldwide, the number of pedestrians killed every year on the road exceeds 400,000.

In France, national statistics show that almost 30% of pedestrian crashes occur at signalized crosswalks (ONISR, 2011). Signalized intersections with crosswalks appear to help channel pedestrian traffic but prove unable to persuade pedestrians to comply with the signal indications (Sisiopiku & Akin, 2003). Studies on adult pedestrian behavior at signalized crosswalks actually show a high level of irregular crossings, especially when pedestrians deliberately choose dangerously short gaps to cross against the light (Koh & Wong, 2014) and when they cross in the last seconds of the pedestrian red light (King, Soole, & Ghafourian, 2009). To understand such illegal crossings and red light violations, many authors have investigated the effects of both external environment and internal human factors, but with more emphasis on external factors.

Red light violations are frequently associated with road and traffic characteristics, such as vehicular traffic conditions (Guo, Gao, Yiang, & Jiang, 2011; Sisiopiku & Akin, 2003; Wang, Guo, Gao, & Bubb, 2011; Yagil, 2000; Yang, Deng, Wang, Li, & Wang, 2005), waiting time (Brosseau, Zangenehpour, Saunier, & Miranda-Moreno, 2013; Guo, Wang, Guo, Jiang & Bubb, 2012; Li & Fernie, 2010; Tiwari, Bangdiwala, Saraswat, & Gauray., 2007; Van Houten, Ellis, & Kim, 2007), or length of the crossing (Cambon de Lavalette, Tijus, Poitrenaud, Leproux, Bergeron, & Thouez, 2009; Cinnamon, Schuurman, & Hameed, 2011).

Individual characteristics such as gender and age have also been shown to be important contributing factors to pedestrian violations, gender having been more studied than age. Male pedestrians are observed and reported to violate traffic rules more frequently than females and are more likely to cross in riskier situations (Guo et al., 2011; Hamed, 2001; Moyano Diaz, 2002; Rosenbloom, 2009; Rosenbloom, Nemrodov, & Barkan, 2004; Tiwari et al., 2007; Tom & Granié, 2011). In a recent study, Ren et al. (2011) show a contradictory finding: they observe male pedestrians to be more likely to comply with traffic rules on signalized crosswalks whereas female pedestrians (especially those who are middle-aged) tend to cross streets in a hurry, once they find a gap to cross, regardless of other unforeseen events.

Age has been much less studied as a factor influencing violation behaviors. The overrepresentation of older pedestrians in crash statistics is often explained by altered decision-making and gap-acceptance processes in situations where no helping signals or markings are provided (see e.g., Dommès, Cavallo, Dubuisson, Tournier, & Vienne, 2014; Dommès, Cavallo, & Oxley, 2013; Dommès & Cavallo, 2011; Holland & Hill, 2010; Oxley, Fildes, Ihsen, Charlton, & Day, 1997; Oxley, Ihsen, Fildes, Charlton, & Day, 2005). Whereas many studies show that older drivers are able to compensate for their reduced abilities to still drive safely (by driving less, more slowly, for example), such adaptive behaviors have rarely been examined in older pedestrians. Indeed, they might also adapt their crossing strategies to adjust for sensory, cognitive and motor changes they are experiencing by using signalized crosswalks and having a greater respect for traffic rules. The rare studies on this topic show that older pedestrians (>60 years) wait for a longer time than younger ones at crossing signals (Guo et al. 2011) and they also appear to be more inclined to comply with traffic laws (Granié, Pannetier & Guého, 2013; Ren et al., 2011; Rosenbloom et al., 2004). But in several other studies, age fails to yield significant differences in offending crossing behaviors (see e.g. Rosenbloom, 2009).

If pedestrian demographic characteristics contribute to red light violations, the particular contextual characteristics in which pedestrians are crossing may do so even more. For example, Rosenbloom (2009) shows that the level of pedestrian density, i.e. the number of pedestrians waiting to cross together (group size), is an important factor in red light violations: the higher the number of pedestrians present at the curb, the lower the rate of people crossing on the red light (Rosenbloom, 2009; Brosseau et al., 2013). But Ren et al. (2011) show contradictory findings: pedestrians who cross in a group tend not to obey the traffic signal. The presence of parked vehicles near the crosswalk is another contextual characteristic that may also be related to pedestrian safety. While the scientific literature points to the presence of parked vehicles as a causal factor in pedestrian accidents, especially among children (Brenac, Nachtergaële, & Reigner, 2003; Roberts, Norton, Jackson, Dunn, & Hassall, 1995; Stutts, Hunter, & Pein, 1996), only a few studies have explored the effect of parked vehicles on adult pedestrian crossing behavior. Tom and Granié (2010) show that adult pedestrians display more cautious crossing behavior when there are no parked vehicles in the area (crossing diagonally less often, starting and finishing on the pedestrian crossing) and are more focused on traffic in the presence of parked vehicles. However, a very recent study found contradictory results: the presence of illegally parked vehicles makes the adult pedestrians more careful (measured by larger gap acceptance) and discourages them from crossing the street (Yannis, Papadimitriou & Theofilatos, 2013). Better knowledge is thus needed about the effects of parked vehicles on pedestrian behaviors before and during crossings, including red light violations.

One last possible factor behind age and gender differences or behind traffic-related characteristics in pedestrian accident statistics and safety-related behaviors is mobility patterns. Driver experience has been shown to influence a number of skills involved in pedestrian crossing, such as visual search (Underwood, Chapman, Bowden, & Crundall,

2002), judging vehicle arrival times (Carthy, Packham, Salter, & Silcock, 1995), and making safe crossing choices (Holland & Hill, 2010). Likewise, walking experience may play a role in the way pedestrians behave on roads, despite the lack of studies on this specific topic. Negative experiences on the road, such as falls and accidents experienced as pedestrians, could influence behaviors as well, particularly the visual attention given to approaching vehicles when crossing (Avineri, Shinar, & Susilo, 2012; Job, Haynes, Prabhakar, Lee & Quach, 1998; Scheffer, Schuurmans, Van Dijk, Van der hooft, & De Rooij, 2008; Woollacott, & Tang, 1997).

Beyond simulator studies about pedestrian crossing behavior (see e.g., Dommes et al., 2014 ; Meir, Parmet, & Oron-Gilad, 2013; Oxley et al., 2005; Schwebel, Stavrinou, Byington, Davis, O' Neal, & de Jong, 2012; Tapiro, Meir, Parmet, & Oron-Gilad, 2014), most of the field studies led in real environments employ methodology such as video analyses (Brosseau et al., 2013; Hamed, 2001; Tiwari et al., 2007; Zhuang & Whu, 2011, 2012), observation grids (Cinnamon et al., 2011; Rosebloom, 2009) or questionnaires alone (Moyano Diaz, 2002; Yagil, 2000). Sisiopiku and Akin (2003) did use video analyses as well as questionnaires, but to study the reasons behind a pedestrian's choice to cross at a specific location. Guo et al. (2011) also used both observations and questionnaires, but only some of the observed pedestrians were questioned. Finally, Ren et al. (2011) analyzed videos combined with questionnaires, but with different participants.

The present study aims to fill gaps in research on adult pedestrian behaviors at signalized intersection crossings, including red light violations, by studying human factors under three aspects: i) the individuals' demographic characteristics (age and gender); ii) the context in which individuals cross the street (group size, presence of parked vehicles, traffic density); iii), and general mobility patterns of these individuals. To meet these objectives, the present study combines observational data (collected during the pedestrian's crossing) and subjective

data from the same pedestrian (collected from his or her answers to an on-site questionnaire, mostly related to mobility patterns). This unique database may allow the analysis of several related human factors to better understand the reasons why pedestrians cross against the signal and sometimes behave dangerously on signalized crosswalks.

2. Methods

2.1. Location of observations

Fifteen urban crosswalks located at six different signalized intersections in the city of Lille, in the north of France, were chosen as experimental sites. All were on two-way streets, with no pedestrian refuge islands. They all had zebra crossings, pedestrian and traffic lights, and a speed limit of 50 km/h on each road segment. Traffic density was available for each observed crosswalk in three categories, measured by the metropolitan community as the average annual daily traffic (AADT): from 1,500 to 6,000 vehicles per day (4 crosswalks), from 6,001 to 13,000 vehicles per day (4 crosswalks) and from 13,001 to 30,000 vehicles per day (7 crosswalks).

2.2. Observation grid and questionnaire

A grid was used to observe pedestrian behaviors during all the crossing task phases (Tom & Granié, 2011). This grid was designed to follow each participant from the curb approach to the very end of the crossing. Such a division into three areas stems from Geruschat et al. (2003), who found that crossing a street is done in three phases: walking to the curb (from 5 to 0.5 meters before the marked crosswalk), standing at the curb (preparation to the crossing), and the crossing itself (from the start of the pavement to the opposite curb).

The observation grid was based on previous works and adapted to observe pedestrian behaviors on French crossroads (Granié, 2007; Latrémouille, Thouez, Ranou, Bergeron, Bourbeau, & Bussière, 2004; Rivara, Booth, Bergman, Rogers, & Weiss, 1991; Routledge, Repetto-Wright, & Howarth, 1974; Van der Molen, 1983; Zeedyk & Kelly, 2003). Pedestrian

red light violation, waiting position (on the curb versus on the road), walking pace (running behavior) and crossing path (straight or diagonal) were observed. Head movements referred to four targets indicating what the head was turned toward: i) the pedestrian light, ii) the moving vehicles, iii) other pedestrians, iv) the ground. Those head movements were not mutually exclusive, and individuals could look at the four targets before and/or while their crossings were observed. Items of the observation grid were presented in chronological order to facilitate the experimenter's task on site. In the version used for the present study, the observation grid was composed of 54 behaviors distributed among 13 behavioral categories (see Appendix).

Observations were made without the pedestrians' knowledge. Two investigators were present on the site, facing the crossing pedestrians. The first investigator described real-time observable behaviors into a dictaphone. Once the observed pedestrians had crossed the road, the second investigator came into contact with them and asked them to answer a few questions, allowing to record the actual age of the participant as well as several mobility-related indicators: i) mobility patterns of the observed pedestrian in terms of frequency of walking and driving; and ii) difficulties experienced by the individual in terms of crossing, falls and accidents as a pedestrian. Behaviors observed on site and variables collected from the questionnaire were coded as described in Table 1.

[TABLE 1]

2.3. Data analysis

Phi coefficients have been calculated to study the relationships between all behaviors, before and while crossing. The Phi coefficient is a measure of the degree of association between two binary variables, similar to the correlation coefficient in its interpretation. Logistic regressions were then computed on each of the 12 behavioral indicators observed before and while crossings, as a function of the ten demographical, contextual and mobility-related variables, and a 13th regression analysis was carried out to examine illegal crossings at

red lights more specifically. For all logistic regression analyses, the predictive factors were automatically entered one at a time using the forward stepwise method, where non-significant predictive factors were removed until the final model yielded only the most significant effects. Binary logistic regression is a useful method of modelling the event probability for a categorical response variable with two outcomes (e.g. running/not running while crossing the street). Several statistics were used to interpret our results. The first three were to test i) the significance of the model itself (chi-square with a p value of less than 0.05); ii) the variability in the dependent variable that could be explained by the model (Nagelkerke's pseudo r -squared ranging from 0 to 1); and iii) whether the model adequately described the data (Hosmer-Lemeshow goodness-of-fit statistic with a p value of more than 0.05). Subsequently, odds ratio (OR) were used to determine the probability that the categorical response outcome variable will occur given the particular exposure to a predictive factor (range between 0 and infinity). An OR equal to 1 means that exposure does not affect odds of the outcome; an OR greater than 1 means that exposure is associated with higher odds of the outcome; and an OR lesser than 1 means that exposure is associated with lower odds of the outcome.

3. Results

3.1. Descriptive statistics

Among the 680 observed pedestrians, 422 accepted to answer the questionnaire after having crossed (201 men and 221 women). Tables 2 and 3 present descriptive statistics for analyzed variables. The distributions of participants for each age group were roughly equally distributed (see Table 2): young (18-29 years), middle-aged (30-49), mature (50-64), old (65-74) and very old pedestrians (>75) respectively account for 17, 23, 17, 24 and 19 % of the sample, with almost the same number of men and women in each age group, except for the 18-29 years-old group (more women).

Table 3 shows that group size and the presence of parked vehicles were equally distributed between the two possible situations. On the contrary, the traffic density variable was not equally distributed among participants: most of the pedestrians were observed at medium to heavy traffic density streets. Mobility patterns also differed: whereas driving experience was equally distributed, most of the observed pedestrians said they walked at least once a day; few of them stated having difficulty crossing a road, and having already fallen in the street or having experienced an accident as a pedestrian in their life.

Descriptive statistics of behavioral indicators show that before crossing, most of the observed pedestrians did not run when approaching the curb (22.7% did run). Most of them did not look toward the ground (10.4% did) or toward the other people around them (9.5% did), but were rather looking toward the approaching traffic (60%) and the pedestrian light (74.4%). Pedestrians were generally waiting on the curb (8.8% were waiting directly on the roadway). While crossing, pedestrians were generally walking (6.9% were running). Only half of the observed pedestrians looked toward the ground (42.7%) or toward the approaching traffic (47.9%), and they generally did not look toward the other people around them (13.5% did) or toward the pedestrian light (18.3% did). Most of the pedestrians crossed straight across (18% crossed diagonally). Finally, a little more than two thirds of the observed pedestrians (68%) complied with the pedestrian light.

[TABLES 2 and 3]

3.2. Phi Coefficients between behavioral indicators

Phi coefficients (see Table 4) indicate a continuity in time between each of the targets looked before crossing and while crossing: pedestrians who were observed to look toward the ground, the traffic, the other pedestrians, or the light before crossing were observed to also look at the same targets while crossing. Moreover, comparisons between the targets looked show that, before crossing, the more pedestrians looked toward the ground, the more they

looked toward the traffic, the other people around them, and the light. However, while crossing, the more they looked toward the ground, the less they looked elsewhere. Comparisons between looked targets also reveal that before crossing as well as while crossing, the more pedestrians looked toward the traffic, the less they looked toward the light. Results furthermore show that risky behavior such as running while crossing was negatively associated with looking toward the light before crossing, but positively associated with risky waiting position before crossing (on the roadway) and with diagonal crossing path. Finally, red light crossing was positively associated with looks toward the traffic before and while crossing, and with other risky behaviors while crossing such as running and crossing in diagonal, but it was also associated with lower gazes toward the light before and while crossing.

[TABLE 4]

3.3. Models A to F: Pedestrian behaviors before crossing as dependent variables

As shown in Table 5, stepwise regression models of behavior *before* crossing were all significant and explained from 10 to 44% of the variance. Results of Model A show that the probability that a pedestrian would run while approaching the curb was significantly associated with demographic variables: younger pedestrians and males were more likely to run while approaching the curb. The probability of looking toward the ground before crossing was significantly higher for older people and when traffic was heavier, and lower in the presence of parked vehicles (Model B). The likelihood that pedestrians would look toward the vehicles before crossing was higher when traffic was heavier and when they were regular drivers, but lower when vehicles were parked near the crosswalk (Model C). Model D demonstrates that the probability that a pedestrian looked toward the other people around him or her while approaching the curb was significantly associated with previous falls and the three contextual variables: they were more likely to look toward the other people when they

walked in group and when traffic was heavier and, on the other hand, they were less likely to do so in the presence of parked vehicles. Looking toward the light before crossing was significantly and positively associated with older pedestrians and heavier traffic. On the contrary, the probability of looking toward the light before crossing was lower when pedestrians walked regularly and when vehicles were parked near the crosswalk. Finally, Model F shows that waiting to cross on the roadway was positively associated with age (younger pedestrians) and gender (women).

3.4. Model G-L: Pedestrian behaviors while crossing as dependent variables

As shown in Table 5, stepwise regression models of behavior *during* crossing were all significant and explained from 5 to 23% of the variance. Model G shows that pedestrians were more likely to run when they were younger and when traffic was heavier. The probability of looking toward the ground while crossing was higher if there were no parked vehicles nearby (Model H). The probability of a pedestrian to look toward the traffic while crossing was significantly associated with pedestrians crossing alone and with parked vehicles near the crosswalk (Model I). Pedestrians were more likely to look toward other people while crossing when walking in groups and when they had already experienced falls. In contrast, the probability of looking toward other people while crossing was lower when vehicles were parked near the crosswalk (Model J). Model K demonstrates that looking toward the light while crossing was significantly associated with heavier traffic and observed among pedestrians reporting difficulty to cross a road. Finally, the probability of crossing diagonally was higher when traffic was heavier, and it was lower when the pedestrian declared difficulty in crossing a road (Model L).

[TABLE 5]

3.5. Model M: red light violation as the dependent variable

A last stepwise logistic regression analysis was carried out to examine more precisely red light crossing behaviors, in connection with demographic, contextual, and mobility-related factors, as well as behaviors before and while crossing.

Final results of the stepwise regression analysis (see Table 5) show that demographic factors (age and gender) did not explain red light crossings; neither did traffic density. The variables linked to individual mobility were not significant either. Two of the contextual factors explained red light crossings: the probability of crossing against the light was more important when pedestrians crossed alone rather than in groups, and when vehicles were parked near the crosswalks. Furthermore, several behavioral indicators were particularly associated to red light crossings. The probability of crossing against the light was associated with three major precursor behaviors: pedestrians who crossed against the signal were more likely to look toward the traffic before crossing but less likely to look toward the light or toward the ground before crossing. Red light crossings were also associated with three behaviors observed during the crossing phase: pedestrians who crossed against the light were more likely to run while crossing, to look toward the traffic while crossing, and to cross diagonally.

4. Discussion

The purpose of the present study was to gain knowledge about the human factors associated with the safety of adult pedestrian behaviors at signalized crosswalks.

4.1. The influence of demographical variables on behaviors

Among demographical variables, the pedestrians' age appears to play a significant role in five crossing behaviors. Results showed that older pedestrians tended to be more cautious than their younger counterparts. The older the pedestrians were, the less they were observed to run while approaching the curb and while crossing, the more often they looked toward the

light and the ground before crossing, and the more they waited on the sidewalk rather than on the roadway.

Although we did not studied the oldest age category specifically, these findings are in line with the few available observational studies (Avineri et al., 2012; Guo et al., 2011; Job et al., 1998; Ren et al., 2011) and they may illustrate compensation strategies against age-related motor, sensory and cognitive difficulties among the oldest pedestrians. To compensate for their reduced abilities to walk (see e.g., Shkuratova, Morris, & Huxham, 2004) and because of their need to maintain their balance while they walk (Woollacott, & Tang, 1997), they do not run before and while crossing. Given their fear of falling (e.g., Scheffer et al., 2008), they also look toward the ground more often, to control their locomotion. Recently, a study demonstrated that older pedestrians pay more attention to their steps as they cross, causing them to neglect the approaching traffic (Avineri et al., 2012). Moreover, to compensate for their reduced abilities to hear (see e.g., Chisolm, Willott, & Lister, 2003) and see (see e.g., Faubert, 2002), as well as to choose a safe gap in which to cross (Dommes et al., 2014), older pedestrians have to look toward the light before crossing more often and comply with traffic rules. Therefore, they seem to delegate the responsibility of their behaviors and choices to the drivers and the infrastructure. These compensation strategies could be the reasons why older pedestrians show more appreciation than younger ones for controlled pedestrian crosswalks and signalized intersections (Bernhoft, & Carstensen, 2008). If age did not emerge as a direct significant predictor of red light violations when behavioral indicators were taken into account, it is also because respecting the signalization helped older pedestrians compensate for age-related reduced abilities. Age alone could not explain why pedestrians violated or did not violate the signal, but it influenced the way pedestrians behaved, looked toward the environment and walked, these behaviors allowing, in turn, for the possibility of crossing against the light.

As in the study by Ren et al. (2011), gender did not emerge in our results as an important factor in crossing behaviors, except for two of them: running (more often observed in men) and waiting on the roadway (more often observed in women). These results are not in line with previous research, generally showing important gender differences in pedestrian behaviors, both reported by pedestrians and directly observed in real situations (Moyano Diaz, 2002; Rosenbloom, 2009; Rosenbloom et al., 2004; Tom & Granié, 2011; Yagil, 2000). Our results, as those found by Ren et al. (2011), only concern signalized crosswalks: it may be that gender differences are less observable in crossing situations regulated by a light. Further explorations of gender differences in crossing behaviors are needed to understand if traffic and pedestrian lights reduce men's violation of crossing rules, or, to the contrary, increase violations among women.

4.2. The influence of contextual variables on behaviors

The three analyzed contextual variables were found to be important factors, with group size and traffic density being related to safer behaviors and the nearby presence of parked vehicles to riskier ones. Pedestrians walking in groups looked toward the other pedestrians before and while crossing more often than alone pedestrians, but they were less vigilant of oncoming traffic while crossing and were more likely to comply with the pedestrian light. The higher number of rule compliance behaviors when pedestrians cross in a group is in line with some previous results on observed behaviors (Brosseau et al., 2013; Rosenbloom, 2009; Zhuang & Wu, 2011) and on intention to cross (Zhou & Horrey, 2010; Zhou, Horrey & Yu, 2009). In younger as in older pedestrians, the presence of other people when crossing seemed to exert a temporary social control (Hirschi, 1969), bringing greater compliance with traffic rules even if, as the lack of gaze toward light shows, they seem to favor social information, which is not always reliable, over non-social information from the traffic control system

(Faria, Krause, & Krause, 2010). Results of the present study suggest that group influence has to be further explored throughout adulthood and in different social and cultural contexts.

Higher traffic density also appears to influence the way pedestrians look toward the scene before and while crossing: in this situation, pedestrians were observed to be more likely to look toward the ground, the traffic, the other people and the light before crossing, as well as running while crossing. All these behaviors may have been the consequence of the fear of being surprised by the change of the traffic light and by incoming traffic, as suggested by the higher frequency of looks toward the light during crossings where traffic density was high. Our results did not show a link between traffic density and red light violations, as it did in previous studies suggesting more violations with lower traffic density (Guo et al., 2011; Sisiopiku & Akin, 2003; Yagil, 2000). High traffic density may actually have contradictory effects. On the one hand, the waiting time for the pedestrian green light may be longer, and may therefore encourage pedestrians to violate the light. On the other hand, opportunities to cross between the heavier moving traffic are rare, which can reduce the number of red light violations.

Results also showed that the nearby presence of parked vehicles tended to inhibit looking behaviors and to increase the probability of crossing against the light. The presence of parked cars decreased the probability of looking toward the ground, the traffic, the other people, and the light before crossing. While crossing, however, pedestrians tended to look toward the approaching traffic more often, probably to verify their decision because they were more prone to cross against the red light. These results are consistent with those of Tom and Granié, (2010) but are not in line with those of Yannis, Papadimitriou, and Theofilatos (2013) showing more cautious behaviors when vehicles are illegally parked near the place of crossing. This discrepancy may be linked to crossing situations. Yannis et al. (2013) observed pedestrian mid-block crossings against the red light outside signalized crosswalks and

sometimes near and/or between illegally parked vehicles. In contrast, crossings observed in the present study took place on marked crosswalks and vehicles were parked legally around them. Pedestrians may adopt much more cautious behaviors in dangerous situations like the ones studied by Yannis et al. (2013) than in the safe infrastructures of the present study. In the present situations, the presence of parked vehicles may increase the pedestrians' feeling of safety (by decreasing the width of the roadway) and generate red light violations. In addition, the visual obstruction created by parked vehicles can cause pedestrians to further verify if there is incoming traffic while crossing (Tom & Granié, 2010).

Mobility-associated variables were also shown to play a role in behaviors. Driving experience seemed to increase safe behaviors and vigilance: pedestrians who were regular drivers were observed to look toward the approaching traffic before crossing more often than pedestrians without driving experience. This result is in line with previous studies showing the effect of driver's experience on visual scanning skills (Underwood et al, 2002) and on time gap choices as pedestrians (Holland & Hill, 2010).

Perception of their own frailty seems to increase the pedestrians' dependency on the infrastructure and on other people: pedestrians who declared experiencing difficulty in crossing a road were about twice as likely to look toward the light while crossing as pedestrians experiencing no difficulty. They also tended to cross straight across the road, rather than diagonally. Moreover, pedestrians who already experienced falls in the street were about three times as likely as pedestrians who had never fallen to look toward neighboring people before and while crossing. Additional analyses indicated that crossing difficulties and falls were mostly reported by the oldest pedestrians. These findings are in line with results about ageing effects previously mentioned and showing that age alone is not as important as experience and perception of our own abilities.

4.3. Toward the understanding of pedestrian red-light violation at signalized intersections

Finally, a wider regression analysis made specifically on red light violations and including behaviors that pedestrians displayed before and while crossing showed that crossing against the light was not directly influenced by age, gender or mobility-associated variables, but by two contextual factors (group size and parked vehicles) and by several crossing behaviors. Illegal crossings appeared to be predetermined by the way pedestrians looked around. Compared to pedestrians who complied with the light, pedestrians who crossed against the red light looked less toward the ground and the light, but more toward the traffic before crossing. It seems that pedestrians' red light violations are anticipated before their arrival at the intersection to cross, on the basis of traffic conditions and without taking into account the color of the pedestrian light, as those pedestrians less looked toward the light before crossing. Additionally, compared to pedestrians who complied with the light, pedestrians who crossed against the red light were observed to run and cross in diagonal more often, but they were also shown to look more toward the traffic while crossing.

These behavioral crossing patterns are in line with previous studies showing that saving time and convenience are the major reasons pedestrians give to explain why they violate the rule (Ren et al., 2011; Zhou, Ren, Wang, Zhang, & Wang, 2011). In the present study, behaviors observed before and while crossing could also reveal a deliberate time-reduction objective, where intentional red light violation goes hand in hand with vigilance of incoming traffic before and while crossing suggesting an awareness of the risk that pedestrians take. The role of two gaze targets (light and traffic) should be particularly further explored.

4.4. Future research

While the present study provides new evidence-based results, there are confounding factors that need further investigation. Pedestrian risk taking behavior and preference is an interesting issue to consider and precisely measure in further studies, in particular to understand the behavioral patterns our results show. Other factors affecting crossing behaviors such as

pedestrian distraction (e.g., use of cell phone/texting) can be considered in follow up studies. So far, this has been addressed by only a few researchers (Zhuang & Wu, 2011; Schwebel et al., 2012), whereas cell phone use becomes a safety issue for pedestrians. Another limitation of our study is to only consider traffic density, which is a daily mean indicator of traffic flow therefore not reflecting traffic conditions at the time of the observed crossings. Even if regulated crosswalks minimize potential conflicts between road users, adding a conflict measure such as the observation of interactions between pedestrians and drivers on sites (Latrérouille et al., 2004) might also improve our models. Finally, combining objective observational data, collected as precisely as possible (with video cameras for example) on all stages of the pedestrians' crossing, and subjective data from the same pedestrians (collected through an on-site questionnaire for example) is a promising means to continue studying human factors linked to crossing behaviors at signalized and unsignalized crosswalks.

5. Conclusions

Findings of the present study highlight the importance of both contextual and individual variables in the crossing behaviors of adult pedestrians. Several conclusions can be drawn to improve pedestrian infrastructures; more than 30% of all the observed crossings took place while the light was red. By increasing visibility (removing parked vehicles) and reducing time spent on the road, infrastructures such as sidewalk extensions and narrower lanes should be part of the solution and might encourage light compliance among pedestrian and driver behaviors (Ewing, 1999; Zegeer et al. 2002).

The oldest pedestrians raised the particular issue of their fear of falling, explaining their focus on the ground instead of on the incoming vehicles, that can be problematic where crossing is not regulated by lights. Improving the crossing pavement quality, the sidewalk and the curb ramp, especially where there are pedestrian lights and crossings, might help to reduce this fear and bring the oldest pedestrians to favor these sites of crossing (Bernhoft &

Carstensen, 2008; Liu, in press). Taking care of the most vulnerable road users when designing intersections, programming traffic light cycle and promoting training for subpopulations (elders, children) should be a priority for local governments, in order to reinforce accessibility for all in our cities.

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APPENDIX. The observation grid (from Tom & Granié, 2011)

1. Pace of the pedestrian while approaching the curb (5-0.5 m)	Stops Slows down Runs Regular walking rhythm
2. Crossing site	False start At the zebra crossing Less than 5 meters from the zebra crossing Less than 5 meters from the zebra crossing between parked cars More than 5 meters from the zebra crossing More than 5 meters from the zebra crossing between parked cars
3. Total number of pedestrians waiting to cross	Single pedestrian 2 pedestrians 3 to 5 pedestrians More than 6 pedestrians
4. Pace of the participant at the curb (0.5-0 m)	Stops Slows down Runs Regular walking rhythm
5. Head movement(s) before crossing	Toward the lights Toward the moving vehicles Toward the other pedestrians Toward the ground
6. State of the lights at the beginning of the pedestrian's crossing	Green traffic light Orange traffic light Red traffic light Green man Red man
7. Starting position of the pedestrian	Sidewalk Pavement
8. Starting crossing in the zebra crossing	Yes No
9. Pace of the pedestrian at the middle of the crosswalk	Stops Slows down Runs Regular walking rhythm
10. Head movement(s) during crossing	Toward the lights Toward the moving vehicles Toward the other pedestrians Toward the ground
11. If there is an interaction with a driver when crossing	Visual contact Gestures / words (friendly, hostile or neutral) Leaves the right of way to the vehicle Other
12. Ending crossing in the zebra crossing	Yes No
13. Crossing path	Straight line Diagonal Between stopped vehicles on the pavement Other (specify)

Table 1. Modality description for each variable considered in this study

Categories	Variables	Descriptions and coding methods	
<i>Demographic</i>	Age (in years)	1: 18-29; 2: 30-49; 3: 50-64; 4: 65-74; 5: >75	
	Gender	0: male; 1: female	
<i>Context</i>	Group Size	0: the pedestrian was crossing alone; 1: the pedestrian was crossing with at least one other pedestrian	
	Parked Vehicles	0: no parked vehicles at the starting point; 1: vehicles parked around the signalized crosswalk	
	Traffic density (vehicles per day)	1: 1,500 – 6,000; 2: 6,001 – 13,000; 3 : 13,001 – 30,000	
<i>Mobility</i>	Driving experience	0: the pedestrian did not report using a car at the moment when s/he was interviewed; 1: the pedestrian reported using a car	
	Walking experience	0: the pedestrian reported walking less than once a day; 1: the pedestrian reported walking at least once every day	
	Crossing difficulty	0: the pedestrian reported finding it easy to cross a road; 1: the pedestrian found it hard	
	Fall	0: no reported falls; 1: at least one reported fall	
	Pedestrian accident	0: no reported accident; 1: at least one reported accident	
<i>Behavioral indicators</i>	Before crossing	Running	0: the pedestrian was not running while approaching the curb; 1: the pedestrian was running
		Looking toward the ground	0: the pedestrian was not looking toward the ground while approaching the curb; 1: the pedestrian was looking toward the ground
		Looking toward the traffic	0: the pedestrian was not looking toward the traffic while approaching the curb; 1: the pedestrian was looking toward the traffic
		Looking toward people	0: the pedestrian was not looking toward people around him/her while approaching the curb; 1: the pedestrian was looking toward people
		Looking toward the light	0: the pedestrian was not looking toward the pedestrian light while approaching the curb; 1: the pedestrian was looking toward the light
		Waiting position	0: the pedestrian was waiting on the curb; 1: the pedestrian was waiting on the roadway
		While crossing	Running	0: the pedestrian was not running while crossing; 1: the pedestrian was running
	Looking toward the ground		0: the pedestrian was not looking toward the ground while crossing; 1: the pedestrian was looking toward the ground
	Looking toward the traffic		0: the pedestrian was not looking toward the traffic while crossing; 1: the pedestrian was looking toward the traffic
	Looking toward people		0: the pedestrian was not looking toward people around him/her while crossing; 1: the pedestrian was looking toward people
	Looking toward the light		0: the pedestrian was not looking toward the pedestrian light while crossing; 1: the pedestrian was looking toward the light
	Path		0: the pedestrian crossed straight across; 1: the pedestrian crossed diagonally
	Red light violation		0: the pedestrian complied with the pedestrian light; 1: the pedestrian crossed against the pedestrian light

Table 2. Number of participants by gender and age group

		Age					Total
		18-29	30-49	50-64	65-74	>75	
Gender	Men	27	50	39	51	34	201
	Women	43	49	34	50	45	221
Total		70	99	73	101	79	422

Table 3. Descriptive statistics of the contextual and mobility-associated variables

Variable	Level*	N	%
Group size	0	230	54.50
	1	192	45.50
Parked vehicles	0	229	54.27
	1	193	45.73
Traffic density	1	23	5.45
	2	210	49.76
	3	189	44.79
Driving experience	0	211	50
	1	211	50
Walking experience	0	98	23.22
	1	324	76.78
Crossing difficulty	0	331	78.44
	1	91	21.56
Fall	0	331	78.44
	1	91	21.56
Pedestrian accident	0	390	92.42
	1	32	7.58

[Note: * See Table 1 for descriptions of each modality.]

Table 4. Phi coefficients between all safety-related behaviors [Note : **p<.01 and *p<.05]

		<i>Before crossing</i>				<i>While crossing</i>							
		2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
<i>Before crossing</i>	1. Running	.004	-.004	.021	-.169**	.096*	.080	-.082	-.023	.005	.057	.031	.024
	2. Looking toward the ground		.247**	.207**	.147**	-.024	-.031	.223**	-.016	.001	.120*	.002	-.134**
	3. Looking toward the traffic			.066	-.380**	.065	.126**	-.146**	.318**	.054	-.052	.043	.301**
	4. Looking toward the people				.134**	-.043	.008	.015	-.002	.322**	.057	.080	-.066
	5. Looking toward the light					-.202**	-.184**	.242**	-.275**	.136**	.179**	.035	-.413**
	6. Waiting position						.280**	.021	.005	.025	-.060	.182**	.075
<i>While crossing</i>	7. Running							-.196**	.190**	.030	.017	.141**	.235**
	8. Looking toward the ground								-.577**	-.159**	-.209**	-.092	-.283**
	9. Looking toward the traffic									-.129**	-.146**	.032	.329**
	10. Looking toward the people										-.007	.049	-.108*
	11. Looking toward the light											.034	-.140**
	12. Path												.155**
13. Red light crossing													

Table 5. Results of the stepwise regression analyses [Note: Results of the final models are presented, with **p<.01 and * p<.05]

	N°	Model Statistics	R ² Nagelkerke	Hosmer- Lemeshow	Significant Predictive factors	OR
<i>Before crossing</i>						
Runing	A	$\chi^2(2)=39.49, p <.001$	.14	.97	Age Gender	.587** .513*
Looking toward the ground	B	$\chi^2(3)=64.96, p <.001$	.29	.92	Age Parked Vehicles Traffic	1.378* .041* 3.769*
Looking toward the traffic	C	$\chi^2(3)=49.23, p <.001$	.15	.01	Parked Vehicles Traffic Driving Experience	.516* 2.330** 1.591*
Looking toward the people	D	$\chi^2(4)=96.47, p <.001$	.44	.11	Group Size Parked Vehicles Traffic Fall	24.955** .089* 3.032* 3.017*
Looking toward the light	E	$\chi^2(4)=58.74, p <.001$	.19	.27	Age Parked Vehicles Traffic Walking Experience	1.479** .374** 1.962* .405*
Waiting position	F	$\chi^2(2)=17.37, p <.001$	.10	.59	Age Gender	.636* 2.243*
<i>During crossing</i>						
Runing	G	$\chi^2(2)=15.96, p <.001$	.09	.66	Age Traffic	.706* 2.728*
Looking toward the ground	H	$\chi^2(1)=31.92, p <.001$	.10	.07	Parked Vehicles	.318**
Looking toward the traffic	I	$\chi^2(2)=15.35, p <.001$	.05	.60	Group Size Parked Vehicles	.614* 1.750*

Looking toward the people	J	$\chi^2(3)=55.81, p <.001$	.23	.68	Group Size	8.052**
					Parked Vehicles	.435*
					Fall	2.333*
Looking toward the light	K	$\chi^2(2)=19.82, p <.001$	.08	.36	Traffic	2.471**
					Crossing Dificulties	2.109*
Path	L	$\chi^2(2)=12.77, p <.01$	.05	.36	Traffic	1.659*
					Crossing Dificulties	.387*
Red light crossing	M	$\chi^2(8)=139.58, p <.001$	.40	.92	Group size	.476**
					Parked vehicles	2.093*
					Looking toward the ground before crossing	.365*
					Looking toward the traffic before crossing	3.506**
					Looking toward the light before crossing	.356**
					Runing while crossing	3.329*
					Looking toward the traffic while crossing	2.164*
					Crossing Path	3.278*
