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

Dommes, A.[1], Granié, M.-A.[2], Cloutier, M.-S.[3], Coquelet, C.[2], Huguenin-Richard, F.[4]

1. IFSTTAR-COSYS-LEPSIS, 25 Allée des Marronniers, F-78008 Versailles, France
2. IFSTTAR-TS2-LMA, 304 chemin de la Croix Blanche, F-13300 Salon de Provence, France
3. INRS, Centre Urbanisation Culture Société, Laboratoire d'analyse spatiale et d'économie régionale, 385, rue Sherbrooke Est, Montréal H2X 1E3, Canada
4. ENEC UMR 8185 CNRS - Université Paris Sorbonne, 191 rue Saint-Jacques, F-75005 Paris, France

Corresponding author: Aurélie Dommes

IFSTTAR

25 allée des Marronniers

78000 Versailles France

Phone: +33(0)1 30 84 39 43

Fax: +33(0)1 30 84 40 01

E-mail: aurelie.dommes@ifsttar.fr

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 pedestrians. Twelve observed behavioral indicators were extracted, and the roles of several demographical, contextual and mobility-associated variables were examined. The results of the logistic regression analyses carried out on each of the 12 observed behaviors revealed that gender had no major impact on crossing behaviors, but age did, with more cautious behaviors being observed in older subjects. The three contextual variables were also found to be important factors; the number of pedestrians waiting to cross together and traffic density were protective factors, and the presence of parked vehicles near the crosswalks was a risky one. Mobility-associated variables played a role also, with driving experience increasing safety and walking experience increasing confidence. Moreover, perception of their own frailty seemed to increase pedestrians' dependency on the infrastructure and on the other people crossing with them. A wider logistic regression analysis made specifically on red light violations with all variables put together showed that crossing against the light was not directly influenced by age or gender, but by the number of pedestrians waiting to cross together, the presence of parked vehicles near the crosswalk facilities, the way pedestrians looked at the traffic and at the signal before crossing, and the way they walked while crossing. The results of the present study showed that pedestrian light violation is not an opportunistic behavior, but seems to be planned by pedestrians even before they reach the place of crossing in order to save time and distance, but at the expense of safety. The overall results would encourage the development of safer pedestrian infrastructures and engineering countermeasures.

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

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 & Aking, 2003). Studies on 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 (Wang, Guo, Gao, & Bubb, 2011; Yagil, 2000; Yang, Deng, Wang, Li, & Wang, 2005), waiting time (Brosseau, Zangenehpour, Saunier, & Miranda-Moreno, 2013; 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). Low traffic volume appears to be a risk factor for crossing against the light (Guo, Gao, Yiang,

& Jiang, 2011; Sisiopiku & Aking, 2003; Yagil, 2000) and it seems that the longer people have to wait for the pedestrian light to turn green, the more likely they are to cross the street beforehand (Brosseau et al., 2013; Guo, Wang, Guo, Jiang & Bubb, 2012).

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 processes (because of age-related functional deficiencies) in situations where no helping signals or markings are provided (see e.g., Dommes, Cavallo, Dubuisson, Tournier, & Vienne, 2014; Oxley, Fildes, Ihsen, Charlton, & Day, 1997): the consequences of advanced age on the processes that allow a pedestrian to safely cross a street, i.e. the ability to choose a safe gap in traffic, are rather well documented (Dommes & Cavallo, 2011; Dommes, Cavallo, & Oxley, 2013; Holland & Hill, 2010; 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). In several other studies, age fails to yield significant differences in offending crossing behaviors (see e.g. Rosenbloom, 2009). Actually, the ageing comparisons are often made between younger adults and "mature" adults, i.e. individuals aged between 50 and 60 years old (see e.g. Sisiopiku & Aking, 2003; Zhuang & Whu, 2011, 2012). As the consequences of ageing are particularly marked at an advancing age (above 75 years old), older individuals should be included to explore significant differences due to age. Furthermore, older people are often under-represented in the samples studied. For example, Rosenbloom (2009) forms a group of 15 individuals older than 60 years old, from his 1392 observed pedestrian. Zhuang and Whu (2011, 2012) compare 24 "elderly" pedestrians older than 50 years old from their 254 pedestrians observed at unmarked roadways. Finally, for most of the observational studies, participants are assigned to an age group by the observer on the basis of their appearance (e.g., Rosenbloom et al., 2004, 2009), which could be a bias when studying the effects of age.

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 pedestrian crossing behavior. Tom and Granié (2010) show that 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 pedestrians more careful (measured by larger gap acceptation) 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).

The present study aims to fill gaps in research on pedestrian behaviors at 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 the objective of studying human factors linked to red light violations, and more generally to safety-related behaviors at signalized crosswalks, 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). Most of the existing research employs 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; Rosembloom, 2009) or questionnaires alone (Moyano Diaz, 2002; Yagil, 2000) to study crossing behaviors. Sisiopiku and Aking (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) used video analyses combined with questionnaires, but with different participants. 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 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. They were separated in three categories according to their traffic density, or the annual average daily traffic (AADT) measured by the metropolitan community: 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. 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; Tom & Granié, 2011; Van der Molen, 1983; Zeedyk & Kelly, 2003). 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. Items 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 items distributed among 13 behavioral categories.

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 that had already used in another project with older pedestrians (Maestracci, 2011; Maestracci, Prochasson, Vanni, Pene, & Louvet, 2010). The questionnaire allowed the investigators to record the actual age of the participant as well as several mobility-related indicators: i) perception of the environment and of the crossing in terms of ease, safety, amenity and comfort; ii) awareness of the surroundings; iii) mobility patterns of the observed pedestrian in terms of frequency and duration of walking and other modes of transport used; and iv) difficulties experienced by the individual, in terms of walking, falls and accidents as a pedestrian.

2.3. Data analysis

Logistic regressions were then computed on each of 12 behavioral indicators as a function of ten demographical, contextual and mobility-related variables. A 13th regression analysis was finally carried out to examine illegal crossings at red lights more specifically as a function of all variables and behavioral indicators considered in the present study. 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.

2.4. Coding of the variables

Behaviors observed on site and variables collected from the questionnaire were coded as described in Table 1.

[TABLE 1]

3. Results

3.1. Descriptive statistics

Among the 680 observed pedestrians at the 15 selected crosswalks, 422 accepted to answer the questionnaire after having crossed (201 men and 221 women). Tables 2, 3 and 4 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.

Table 3 shows that group size and the presence of parked vehicles are 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.

Moreover, descriptive statistics show that before crossing, most of the observed pedestrians did not run when approaching the curb (22.27% did run). Most of them did not look at the ground (10.43% did) or at other people around them (9.48% did), but were rather observing the approaching traffic (59.95%) and the pedestrian light (74.41%). Pedestrians were generally waiting on the curb (8.77% were waiting directly on the roadway). While crossing, pedestrians were generally walking (6.87% were running). Only half of the observed pedestrians looked at the ground (42.65%) or at the approaching traffic (47.87%), and they generally did not look at the other people around them (13.51% did) or at the pedestrian light (18.25% did). Most of the pedestrians crossed straight across (18% crossed diagonally). Finally, a little more than two thirds of the observed pedestrians (68.01%) complied with the pedestrian light.

[TABLES 2 and 3]

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

As shown in Table 5 (top), regression models were all significant and explained from 11 to 46% of the variance in the behaviors studied. Results of Model A showed that the probability that a pedestrian would run while approaching the curb was significantly associated with both demographic variables and driving experience: younger pedestrians, males, and non drivers were more likely to run while approaching the curb. The probability of looking at the ground before crossing was significantly higher for older people and when traffic was heavy, and lower in the presence of parked vehicles (Model B). The likelihood that pedestrians would look at the vehicles before crossing was higher when traffic was heavy and when they were regular drivers, and lower when vehicles were parked near the crosswalk (Model C). Model D demonstrates that the probability that a pedestrian looked at 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 at the other people when they walked in group and when traffic was heavy and, on the other hand, they were less likely to do so in the presence of parked vehicles. Looking at the pedestrian light before crossing was significantly and positively associated with older pedestrians and heavy traffic. On the contrary, the probability of looking at the light before crossing was lower when pedestrians walked regularly and when vehicles were parked near the crosswalk. Group size was close to the significance level, with a higher probability of looking at the light when pedestrians walked in groups (Model E). Finally, Model F shows that the waiting position was positively associated with age (younger pedestrians) and gender (women).

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

As shown in Table 5 (bottom), the models were all significant and explained from 7 to 23% of the variance of the behavior studied. Model G shows that pedestrians were more likely to run when they were younger, when traffic was heavy, and when they reported no crossing difficulty. Looking at the ground while crossing was only significantly associated with the presence of parked vehicles: the probability of looking at the ground while crossing was higher if there were no parked vehicles nearby (Model H). The probability of a pedestrian to look at 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 at the other people while crossing when walking in groups and when they had already experienced a fall(s) in the street. In contrast, the probability of looking at the other people while crossing was lower when vehicles were parked near the crosswalk (Model J). Model K demonstrates that looking at the pedestrian light while crossing was significantly associated with heavy traffic and observed among pedestrians reporting difficulty to cross a road. Finally, the probability of crossing diagonally was higher when pedestrians crossed in a group. In contrast, it was lower when the pedestrian declared difficulty in crossing a road (Model L).

[TABLE 4]

3.4. Toward the understanding of red light violations

A last logistic regression analysis was carried out to examine red light crossing behaviors with more precision, in connection with demographic, contextual, and mobility-related factors, as well as behaviors before and while crossing, i.e. behaviors that took place before (precursor to) and after (consequence of) a red light violation. The model was significant,

$\chi^2(22)=151.97$, $p<.001$. Nagelkerke's pseudo r-squared statistic showed that 42% of the variance in red light crossings could be explained by the model. The Hosmer-Lemeshow goodness-of-fit statistics indicated that the model adequately described the data (p=.385).

Results of the regression analysis showed 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, except for the fall variable which was close to the level of significance (p=.076). Pedestrians who had already experienced falls in the street were less likely to cross against the pedestrian light (OR=.526). Two of the contextual factors also explained red light crossings: the probability of crossing against the light was more important i) when pedestrians crossed alone rather than in groups (OR=.480, p<.05), and ii) when vehicles were parked near the crosswalks (OR=1.799, p=.069). However, some behavioral indicators were particularly associated to red light crossings. The probability of crossing against the light was associated with two major precursor behaviors: pedestrians who crossed against the signal were more likely to i) look at the traffic before crossing (OR=3.973, p<001) and to ii) not look at the light before crossing (OR=.367, p<.01). Red light crossings were also associated with two behaviors: pedestrians who crossed against the light where more likely to i) run while crossing (OR=4.182, p<.01); and to ii) cross diagonally (OR=3.132, p<.01).

4. Discussion

The purpose of the present observational study was to gain knowledge about the human factors associated with the safety of pedestrian behaviors at signalized crosswalks, and, more specifically, with red light violations.

Among demographic variables, the pedestrians' age appears to play a significant role in safety-related 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 at the light before crossing, and the more they waited on the sidewalk rather than on the roadway. Older pedestrians were also observed to look at the ground before crossing more often than younger pedestrians. 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 older 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 at 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 at 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 at 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. Gender impact was statistically significant only for one of the 13 safety-related indicators: women were observed to run while approaching the curb less often than men. Gender differences were close to the level of significance for another indicator: women were shown to be twice as likely as men to wait directly on the roadway. These results are not in line with previous research, generally showing 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 pedestrian light. Similarly, Sisiopiku and Aking (2003) showed that the observed rate of spatial crossing compliance (e.g., crossing straight across rather than diagonally) is higher at signalized crosswalks compared to unsignalized ones and Rouphail (1984) found a link between pedestrian perception of crosswalk safety and crossing compliance. Greater caution among males on signalized crosswalks might be explained by pedestrian perception of this type of crossroad. Pedestrians may see the presence of traffic lights as a sign of higher danger, of complexity and/or of traffic density, therefore modifying their behavior. Male pedestrians have been found to be more focused on cues related to physical environment, to traffic density and to speed in their decision to cross (Granié, 2007; Tom & Granié, 2011; Underwood, Dillon, Farnsworth, & Twiner, 2007). As traffic and pedestrian lights are preferentially implemented in France on crossings where traffic density is high (CETUR, 1988), this may affect males' crossings more than females', and then reduces male violations of rules on this type of crossing.

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 at the other pedestrians and at the light while waiting on the sidewalk more often. They were also more prone to look at each other while crossing, but were less vigilant of oncoming traffic and tended to cross diagonally more often. Mostly, pedestrians in groups were more likely to comply with the pedestrian light. Pedestrians crossing together were therefore observed to adopt cautious behaviors (to avoid conflicts and falls), but they were also observed to rely on the system (infrastructure and vehicles) to adapt its behavior. 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 but not in terms of trajectory (diagonal versus straight). However, other studies show opposite findings, with more rule-transgressing behaviors in groups of people crossing together, pedestrians favoring social information, which is not always reliable, over non-social information from the traffic control system (Faria, Krause, & Krause, 2010). However, the age of the observed pedestrians in the latter study was not mentioned, while social control mechanisms depend on social norms (Sanna & Shotland, 1990) and therefore on age. The presence of peers, for example, appears to increase risky behavior among pedestrian teenagers (Christensen & Morrongiello, 1997; Miller & Byrnes, 1997), this being an age where risk-taking and transgression are valued (Carsaro & Eder, 1990; Siegel, Cousins, Rubovits, Parsons, Lavery, & Crowley, 1994).

Higher traffic density also appears to increase the way pedestrians look at the scene before and while crossing. Moreover, pedestrians were observed to be more likely to run when traffic was heavy, suggesting that they were aware of the danger of the situation and may have been afraid of being surprised by the incoming traffic, as suggested by the higher frequency of looks towards the light during crossings where traffic density is high. But 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 & Aking, 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 heavy moving traffic are rare, which can reduce the number of red light violations.

Results also showed that pedestrians were less cautious when vehicles were parked near the crosswalk. 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 at the ground, at the traffic, at other people, and at the light before crossing. While crossing, however, pedestrians tended to look at the approaching traffic more often, probably to verify their decision because they were more prone to cross against the red light. These results are not in line with the only available study by Yannis, Papadimitriou, and Theofilatos (2013), that shows 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. The effects of the presence of parked vehicles on the crossing behaviors can be explained in several ways. The visual obstruction created by parked vehicles can cause pedestrians to further verify if there is incoming traffic while crossing. In addition, the presence of parked vehicles may increase the pedestrians' feeling of safety (by decreasing the width of the road) and generate red light violations.

Mobility-associated variables were also shown to play a role in safety-related behaviors. Driving experience seemed to increase safe behaviors and vigilance: pedestrians who were regular drivers were observed to run less and to look at the approaching traffic while waiting on the curb more often than pedestrians without actual driving experience. Indeed, Holland and Hill (2010) recently showed that driving experience has a significant positive effect on the number of safe crossings made in a judgment task where participants indicated their time-gap choices by taking one step forward in a simulator. Similarly, experienced drivers have already been proven to take more elements into consideration when scanning a complex driving scene (Underwood et al., 2002). Walking experience, in contrast, seems to increase confidence, as regular walkers were more likely to disregard the signal before crossing than occasional walkers. This confidence may be related to a better knowledge of the infrastructure and to frequentation of the city where pedestrians said they often walked. This finding needs to be further studied, mostly in the general context of promoting walking to reduce the use of cars and decrease pollution in modern cities.

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 at the light before crossing as pedestrians experiencing no difficulty. They also tended to cross straight across the road, rather than diagonally. Moreover, pedestrians who had already experienced a fall(s) on the street were about three times as likely as pedestrians who had never fallen to look at neighboring people before and while crossing. The people who had fallen were also less likely to cross against traffic light. Additional analyses indicated that crossing difficulties and falls were mostly reported by old 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.

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 safety-related behaviors. Illegal crossings appeared to be predetermined by the way pedestrians looked at the light and the traffic before crossing and while approaching the curb. Compared to pedestrians who complied with the light, pedestrians who crossed against the red light looked less at the light, but more at the traffic. It seems that pedestrians' red light violations are not an opportunistic behavior but are planned even 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. Red light violations were also associated with jaywalking and running while crossing. Previous studies showed that pedestrian violations increase with longer waiting time (Tiwari, et al., 2007; Van Houten, et al., 2007; Wang et al.,2011) but they mostly concluded that saving time and convenience are the principal 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 time-reduction objective, red light violations not being an opportunistic behavior, but seeming to be planned by pedestrians even before their arrival at the intersection to cross, in order to save time and distance at the expense of safety.

5. Conclusions

Our findings highlight the importance of both contextual and individual variables in the crossing behaviors of adult pedestrians. Several conclusions can be drawn to affect the development of safer pedestrian infrastructures; more than 30% of all the observed crossings took place while the light was red. Engineering countermeasures should be part of the solution to reduce red light violations, with, for example, sidewalk extensions and narrower lanes, known to be efficient countermeasures to increase visibility by removing parked vehicles and reducing time spent on the road (Ewing, 1999; Zegeer et al. 2002). Such infrastructures might encourage pedestrian and driver behaviors towards light compliance, as seen in our results. Older pedestrians raised the particular issue of their fear of falling, explaining their focus on the ground instead of on the light and the incoming vehicles while crossing. Improving the pavement quality on the crossing, the sidewalk and the curb ramp, especially where there are pedestrian lights and crossings, might help to reduce these fears and change behaviors (Bernhoft & Carstensen, 2008; Liu, in press). Results of the present study also suggest that training programs might be a way to improve behaviors. A possible efficient approach could be to offer mixed behavioral and educational training, already demonstrated to improve the safety of older pedestrian adults (Dommes & Cavallo, 2012; Dommes, Cavallo, Vienne, & Aillerie, 2012). 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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Table 1. Modality description for each variable considered in this study

Categories	Variables	Descriptions and coding methods
Demographics	Age (in years)	1: 18-29; 2: 30-49; 3: 50-64; 4: 65-74; 5: >75
	Gender	0: male; 1: female
Context	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
Mobility	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
Behavioral indicators		
Before crossing	Running	0: the pedestrian was not running while approaching the curb; 1: the pedestrian was running
	Looking at the ground	0: the pedestrian was not looking at the ground while approaching the curb; 1: the pedestrian was looking at the ground
	Looking at the traffic	0: the pedestrian was not looking at the traffic while approaching the curb; 1: the pedestrian was looking at the traffic
	Looking at people	0: the pedestrian was not looking at people around him/her while approaching the curb; 1: the pedestrian was looking at people
	Looking at the light	0: the pedestrian was not looking at the pedestrian light while approaching the curb; 1: the pedestrian was looking at 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 at the ground	0: the pedestrian was not looking at the ground while crossing; 1: the pedestrian was looking at the ground
	Looking at the traffic	0: the pedestrian was not looking at the traffic while crossing; 1: the pedestrian was looking at the traffic
	Looking at people	0: the pedestrian was not looking at people around him/her while crossing; 1: the pedestrian was looking at people
	Looking at the light	0: the pedestrian was not looking at the pedestrian light while crossing; 1: the pedestrian was looking at 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 light

Table 2. Number of participants by gender and age group

		Age					
		18-29	30-49	50-64	65-74	>75	Total
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. Results of the regression analyses carried out on the 12 safety-related indicators observed before and while crossing

[Note: **p<.01; * p<.05; ## p <.07; # p<.09]

					Demographic		Contextual				Mobility			
		Model	R^2	Hosmer-	Age	Gender	Group Size	Parked vehicles	Traffic density	Driving experience	Walking experience	Crossing difficulty	Fall	Pedestrian accident
	N°	Statistics	Nagelkerke	Lemeshow	OR	OR	OR	OR	OR	OR	OR	OR	OR	OR
Before crossing														
Running	A	$\chi2(10)=50.07$, $p<.001$	.17	.651	**.624****	**.468****	.775	.990	1.401	**.593***	1.566	.745	1.000	.466
Looking at the ground	B	$\chi2(10)=68.26$, $p<.001$	.31	.796	**1.394***	1.121	1.618	**.040****	**3.786****	1.234	1.235	1.515	1.081	1.392
Looking at the traffic	C	$\chi2(10)=52.64$, $p<.001$	.16	.039	.943	.961	.823	**.509****	**2.380****	**1.564***	1.183	.909	1.315	1.147
Looking at people	D	$\chi2(10)=100.67$, $p<.001$	.46	.417	.820	.600	**26.179****	**.083****	**2.562***	.789	1.008	1.150	**3.544****	.294
Looking at the light	E	$\chi2(10)=62.84$, $p<.001$	.20	.677	**1.473****	1.158	**1.534#**	**.393****	**1.974****	.939	**.421***	1.077	1.018	1.282
Waiting position	F	$\chi2(10)=22.11$, $p<.05$	.11	.446	**.656****	**2.093##**	.771	.538	.837	.969	2.087	1.031	.977	.853
While crossing														
Running	G	$\chi2(10)=24.65$, $p<.001$	.14	.321	**.701***	1.286	.672	1.171	**3.348***	.625	.531	**.218***	1.315	2.518
Looking at the ground	H	$\chi2(10)=37.29$, $p<.001$	.11	.074	1.089	1.076	1.129	**.294****	.805	.858	.940	.767	1.040	1.201
Looking at the traffic	I	$\chi2(10)=21.92$, $p<.05$	.07	.184	.968	.882	**.593***	**1.915****	1.307	1.280	1.253	.974	1.046	.917
Looking at people	J	$\chi2(10)=57.70$, $p<.001$	.23	.746	1.088	1.253	**7.788****	**.486***	1.286	1.065	1.001	.716	**2.421***	1.193
Looking at the light	K	$\chi2(10)=26.76$, $p<.01$	.10	.013	1.119	1.470	.969	.823	**2.334****	1.096	.645	**1.891***	.770	.713
Path	L	$\chi2(10)=21.39$, $p<.05$	.08	.994	.886	1.182	**1.585#**	.661	1.228	1.000	1.090	**.427***	.812	.577