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Abstract

The purpose of this study was to identify the influence of situation complexity and driving experience on subjective workload and driving performance, and the less costly and the most effective strategies faced with a hazard pedestrian crossing. Four groups of young drivers (15 traditionally trained novices, 12 early-trained novices, 15 with three years of experience and 15 with a minimum of five years of experience) were randomly assigned to three situations (simple, moderately complex and very complex) including unexpected pedestrian crossings, in a driving simulator. The subjective workload was collected by the NASA-TLX questionnaire after each situation. The main results confirmed that the situation complexity and the lack of experience increased the subjective workload. Moreover, the subjective workload, the avoidance strategies and the reaction times influenced the number of collisions depending on situation complexity and driving experience. These results must be taken into account to target the prevention actions.

Keywords: Subjective workload; Driving experience; Situation complexity.

1. Introduction

Epidemiological studies covering 37 countries show that young drivers are the most involved in road accidents (Organisation for Economic Co-operation and Development (OECD) / International Transport Forum (ITF), 2014). The age is thus an important factor and more precisely the experience inherent in the age, as the accident rate decreases with experience (Mayhew, Simpson, & Pak, 2003) with a high risk the first months and the first kilometres after getting the driving license (McKnight, 2006; Preusser, 2006). During the first eight months, the number of accidents involving novice drivers decreases by approximately 50% (Sagberg, 2000, cited by OECD, 2006), confirming that these road accidents are more linked to their driving experience than to their age.

Situation complexity and hazard events also constitute a major determinant of driving performance. Generally, most fatalities occur on rural roads compared to urban roads and motorways, with 65% of the fatalities in France, 62% in Austria, almost 60% in the United Kingdom, 49% in United States and 48% in Belgium in 2012 (OECD/ITF, 2014). These types of roads define the situation complexity, according to a taxonomy that classifies the elements of a situation as more or less complex (Fastenmeier, 1995). The complexity can thus vary with road geometry (rectilinear vs. curvilinear, flat vs. hilly), roadside environment (quantity and variability of traffic signs, variability of the scenery) and traffic density (low vs. high). Finally, hazard events are broadly observed with pedestrians crossing the road, making them the largest group of vulnerable road users in most countries. The number of fatalities amongst pedestrians slightly increases since 2009 and represents 19% of all fatalities in the 37 countries recorded by the International Traffic Safety Data and Analysis Group (IRTAD) in 2014 (OECDE/ITF, 2014). Data from the Detailed Accident Study collected by the Mechanisms of Accidents Laboratory at IFSTTAR (French Institute of Science and Technology for Transport, Development, and Networks) also precise that unexpected events, such as a pedestrian crossing in front of a driver, correspond to prototypical accident scenarios (Damm, Nachtergaële, Meskali, & Berthelon, 2011). Among several configurations of accidents between a vehicle and a pedestrian, many occur when a pedestrian moves more or less perpendicular to the vehicle path covers (Wisch, Seiniger, Pastor, Edwards, Visvikis, & Reeves, 2013).

Considering that 90% of road accidents are due to human errors (Amditis et al., 2010), the research question concerns the processes involved and particularly the subjective workload, i.e. cost perceived depending on the interaction between required tasks and drivers' internal state (Hockey, 2003). Situation complexity and low driving skills can particularly enhance the drivers' level of subjective workload, leading to performance impairments. Based on the taxonomy of situation complexity (Fastenmeier, 1995), a recent study revealed performance degradations in "urban" sections and "oncoming traffic" sections (complex situations) compared to "rectilinear roads" sections (simple situation), characterized by higher Standard Deviations of the Lateral Position (SDLP) and higher Standard Deviations (SD) of speed (Baldauf, Burgard, & Wittmann, 2009). Meister's model (1976) explains these results by a link between the situation complexity, the level of subjective workload and the performance. When the situation is low demanding (e.g., in long and monotonous roads with a low traffic density), or conversely high demanding (e.g., in rural roads with a high traffic density), the level of subjective workload is high and the performance is impaired, revealing an overload. Indeed, when the level of demand is low, the driver has to provide a high effort to overcome the vigilance decrement and when the level of demand is high, the driver needs to provide a high effort to process the vast amount of information. In these types of situations, the level of workload thus increases with the provided effort, until the driver doesn't have sufficiently available resources to maintain a good performance. However, when the situation is moderately complex (e.g., in rural roads with a moderate traffic density), the level of subjective workload is relatively low. Even if it slightly increases, drivers can adopt the compensatory strategy of reducing their speed in order to correctly perform the task. Accident reports on rural roads provide few details about road characteristics at the time of the accidents. However, it is necessary to identify the potential complex elements of the situation in the aim of better discern the origin of rural roads' accidents.

Workload varies differently depending on driving experience. The Skill, Rule, Knowledge (SRK) model of Rasmussen (1984) shows that driving skills are acquired in three steps with experience. The Knowledge-based behavior, mainly adopted by novice drivers, is a controlled action (slow and effortful) referring to the knowledge about the Highway Code and previous experiences. The Ruled-based behavior is an intermediate step which can be adopted either by novice or experienced drivers. It is a controlled action which follows prescribed rules (e.g., stopping at a red traffic light). The Skill-based behavior is an automatic action (fast and effortless) rather adopted by experienced drivers (e.g., changing gear without attention). This model confirms that novice drivers predominantly have a lack of routine automation (De Craen, Twisk, Hagenzieker, Elffers, & Brookhuis, 2008). Performing the task thus implies producing a higher effort for novices than for experienced drivers (Patten, Kircher, Östlund, Nilson, & Svenson, 2006), this effort reflecting a high level of subjective workload. Consequently, novice drivers are more likely to have accidents when they are overloaded, with a level of workload too high to maintain a good performance.

Three profiles of young French drivers can especially qualify the different levels of experience. Traditional trained drivers have 20 hours of driving lessons with an instructor. Early-trained drivers have an additional driving practice with an adult during 3000 km and can start the learning at the age of 16. These two profiles of novice drivers can both get their driving license from the age of 18. They subsequently have a restricted license including a speed limitation and a restriction to 6 points instead of 12 points on their license. This probationary period, preceding the obtaining of a full license, lasts three years for traditionally trained drivers and two years for early trained drivers. It also appears that drivers with more than five years of experience are three times less likely to have an accident compared to drivers who have just had their driving license (Maycock, Lockwood, & Lester, 1991). Therefore, the overload probably appears earlier with the lack of experience, in the following order for: novice drivers who are traditionally trained, novice drivers who are early-trained, drivers arriving at the end of the three year probationary period, and drivers having more than five years of experience.

Faced with a hazard event with a high temporal pressure as a pedestrian crossing, reacting in time to avoid the vulnerable user becomes difficult. Several strategies can be adopted to avoid the accident, i.e. braking, swerving, making a combination of both of them, or anticipating the hazard appearance by braking, swerving or releasing the accelerator pedal in advance. According to a literature review about possible avoidance maneuvers in emergency situations (Adams, 1994), drivers brake more than they swerve, although braking alone is less effective to avoid any collision than swerving or both braking and swerving.

Age and experience are often combined in driving studies. The present objective is to particularly focus on driving experience by comparing, among young drivers, groups having different levels of experience. The main hypothesis is that combined effects of high temporal pressure inducted by pedestrian apparition, situation complexity (simple or very complex situations) and lack of experience should enhance the level of subjective workload and impair driving performance when drivers are faced with an unexpected pedestrian crossing the road. Performance decrement could be longer reaction times and a higher number of collisions with the pedestrians due to costly and inappropriate avoidance maneuvers as braking alone (Adams, 1994).

2. Methods

2.1. Participants

Fifty-seven young drivers (33 males and 24 females) were divided up into four groups depending on their driving experience. Two groups were composed of novice drivers who obtained their driving license within the last two months. Fifteen novices aged 18-20 (mean = 19, SD = 0.84) were Traditionally Trained Drivers (TTD), with a minimum of 20 hr of driving lessons. Twelve novices aged 18 (mean = 18, SD = 0) were Early-Trained Drivers (ETD), with a minimum of supplementary driving practice of 3 000 km under the monitoring of an adult having a full driving license. The two other groups included more experienced drivers, with 15 drivers aged 21 (mean = 21, SD = 0) arriving at the End of the three-year (more or less 3 months) Probationary Period (EPP), and 15 Experienced Drivers (ED) aged between 23-30 (mean = 26.87, SD = 2.97) with a minimum experience of five years. The participants' recruitment was realized by soliciting driving schools, secondary schools, universities, and university institutes of technologies (UTI). Only participants corresponding to the inclusion criteria were selected, i.e. in good health, with a normal or corrected view, and without any sensitivity to motion sickness. All have signed a written informed consent form and the experimental setup has been approved by the IFSTTAR ethic committee for biomedical research.

2.2. Apparatus

The experiment was carried out on the fixed-base driving simulator of the Laboratory of Accident Mechanisms Analysis (LMA), equipped with a multi-actor parallel architecture for traffic simulation (ArchiSim) and an object database SIM²-IFSTTAR (simulation software) (Espié, Gauriat, & Duraz, 2005). The "ArchiSim" architecture was built on the DR2 traffic simulation model (management of "autonomous" and "enslaved" vehicle with a behavior defined by the scripts for each scenario, simulation generated by captors of punctual and space traffic) and on the 3D SIM2 loop of visualization. The interactive driving station comprised one quarter of a vehicle including a seat, a dashboard, and controls equipped with captors, i.e. pedals and steering wheel (see Fig. 1).

Fig. 1. Driving simulator.

The different movements and actions exerted on the vehicle were virtually reproduced. The acceleration, braking, and steering values of the simulator were those of an average vehicle. The captors installed on the simulator recorded the values in real time. The simulator had an automatic gearbox and was not equipped with rearview mirrors. The image projection (30 Hz) surface, placed on three screens in front of the simulator at 1.93 m of the driver's eye, filled an angular opening that spanned 150° horizontally and 40° vertically. Each screen had a 1280 x 1024 pixels resolution. A sound in quadriphonic diffused in the simulator consisted of internal noise (motor, bearing and starter) and external noise (traffic).

2.3. Experimental situations

Three National roads respecting a width of 3.50 m, corresponding to the international standardization of main roads taking the lateral safety margins as a function of the speeds used into account (Vertet & Giausserand, 2006), were stretched over 22.5 km each (around 15 minutes of driving). According to the taxonomy of the elements characterizing the complexity of a driving situation (Fastenmeier, 1995), two elements have been taken into account in the experiment, i.e. road geometry (rectilinear vs. curvilinear) and traffic density (without vs.

with). The simple situation consisted in a rectilinear national road with two ways, without any traffic. The center marking was a continuous white line. The moderately complex situation included 5 right and 5 left curves (length: 600 m, radius: 300 m). The very complex situation had double and sharper curves (length: 300 m, radius: 120 m), with oncoming traffic. Whatever the situation, three scenarios implying a pedestrian were included. The pedestrians, randomly hidden by a billboard, a bus stop or a tree on the right side of the way, crossed the road around 2.7 seconds before the participant arrived at their level. This time was calculated in such a way that, as soon as the pedestrian appeared in the drivers' visual field, they could brake in time to avoid the pedestrian. Each pedestrian walked at 5 km/hr (walking average speed of an adult, see Seiniger, Bartels, Pastor, & Wisch, 2013) and had a 90° crossing angle, perpendicular at the participants' trajectory.

2.4. Subjective measures

The workload was self-assessed by the NASA Task Load Index questionnaire (Hart & Staveland, 1988) comprising 6 subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration. For each subscale, participants estimated their level of workload during the previous situation on a 20 points scale ranged from 0 = 'very low' to 20 = 'very high'. For the Own Performance subscale, the scale was ranged from 0 = 'success' to 20 = 'failure'. The questionnaire was adapted to the experimental situations. For each subscale, the question concerned the level attributed to the pedestrian crossings.

2.5. Objective measures of driving performance

During the portions with pedestrians, the objective driving behavior was observed by the strategies to avoid the pedestrians (braking, swerving, combination of both braking and swerving, and anticipating), the Reaction Times (RT) of the first action realized after the pedestrians appearances in the driver's vision field, and the number of collisions with the pedestrians. The action of anticipation was defined as the action made just before the pedestrian appearance. This action could be either releasing the accelerator pedal, pressing the brake pedal, or swerving on the right or on the left of the pedestrian. For each situation, swerving was noted when the Lateral Position (LP) of the driver increased from more or less than the mean of the Standard Deviation of Lateral Position (SDLP) observed on all the rectilinear portions of the whole situation. The collisions with the pedestrians did not have a negative impact on the participants who passed through the image without any visual change.

2.6. Procedure

Before the experiment, the participants were trained in order to get accustomed to the simulator as a function of the different tasks which they had to perform during the three situations. They thus had to drive at 90 km/h on a straight line, to turn left, to turn right, and to brake. The training was stopped when they judged it sufficient to feel comfortable with the simulator commands. The three situations were then presented in a counterbalanced order, with the same instruction, i.e. "you will be on a National Road limited at 90 km/h. Drive by respecting the rules of the Highway Code, as in real driving". The NASA-TLX questionnaire was filled out after each situation to collect the subjective level of workload induced by the different driving situations (see Fig 2). The whole experiment lasted around 1h30.

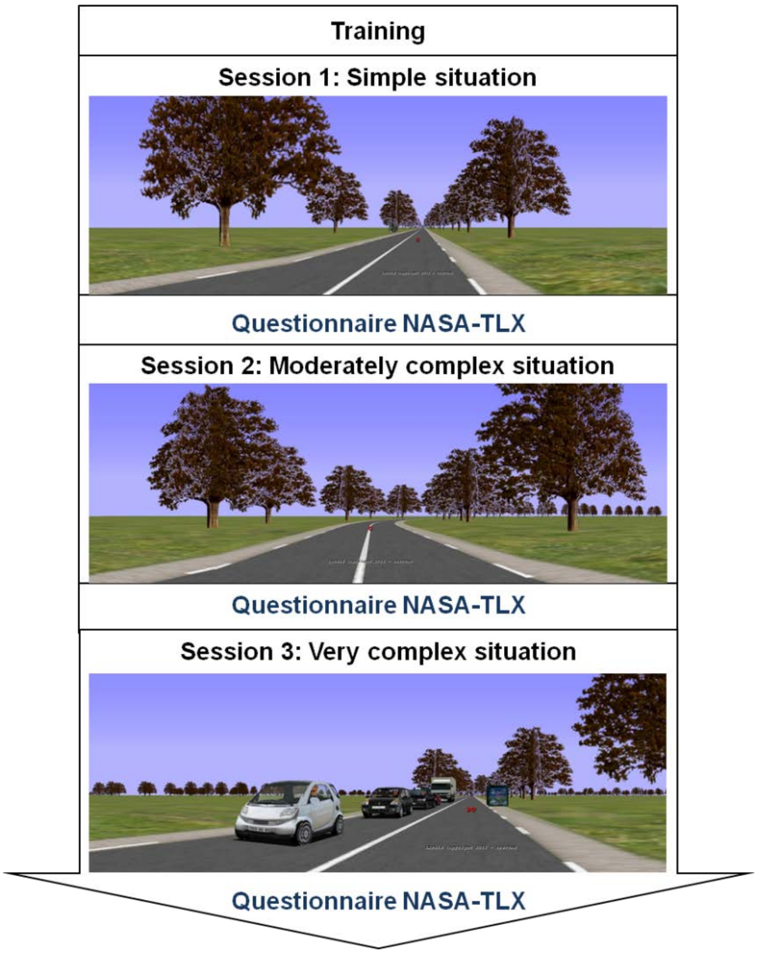

Fig 2. Experimental procedure.

2.7. Statistical analyses

As we observed a significant order effect of the pedestrian appearance on the number of collisions with the pedestrians with a higher number of collisions with the first pedestrian than with the second and the third ones, analyses only took into account the second and third pedestrian appearances which were more expected than the first pedestrian. Therefore, the surprise effect of the first pedestrian appearance was not analyzed.

Four statistical analyses (statistical significance set at $p \leq .05$) were carried out. Second order polynomial regressions were realized on standardized data for all analyses except from the second one. Subsequently, post-hoc analyses were followed with independent samples t-tests for pairwise comparisons, and with simple linear regressions for the effect of a variable on another one in each condition.

The first analysis was on a 4 (driving experience: Traditionally Trained Drivers vs. Early-Trained Drivers vs. drivers at the End of the Probationary Period vs. Experienced Drivers) × 3 (situation complexity: simple vs. moderately complex vs. very complex) × 4 (strategy: braking vs. swerving vs. combination of braking and swerving vs. anticipating) partially crossed design. Indeed, each strategy was not found in each situation. The dependent variable was the subjective workload attributed to pedestrian crossings.

The second analysis followed a 4 × 3 mixed factorial design, with driving experience as a between-participants variable, and situation complexity as a within-participants variable. The dependent variable was the strategy. A repeated measures analysis of variance (ANOVA) was followed by Bonferroni post-hoc tests used for pairwise comparisons.

Before the third analysis, Sobel tests were realized in order to identify the mediation effects, i.e. effects of driving experience and situation complexity on the Reaction Time, mediated by subjective workload. The third analysis was based on a 4 (driving experience) × 3 (situation complexity) × 3 (subjective workload) partially crossed design. The dependent variable was the Reaction Time (RT).

Before the last analysis, Sobel tests analyzed the effects of driving experience and situation complexity on the number of collisions, mediated by subjective workload, strategy and RT. The effect of subjective workload on the number of collisions, mediated by RT was also analyzed. The last analysis thus based on a 1 (subjective workload) × 4 (strategy) × 1 (RT) partially crossed design. The dependent variable was the number of collisions with pedestrians.

3. Results

3.1. Subjective workload attributed to pedestrian crossings

For the mean scores of subjective workload, a 4 (driving experience) × 3 (situation complexity) × 4 (strategy) second order polynomial regression was run. In this model, all the predictors accounted for 13.04% of the variance (adjusted R-squared).

Driving experience significantly influenced the subjective workload (linear effect: β = -.27, p < .001; non linear effect: β = -.23, p < .001). ETD (M = 14.43, SD = 3.62) had higher scores than TTD (M = 12.00, SD = 4.18), EPP (M = 11.42, SD = 3.34), and ED (M = 10.08, SD = 2.91). Moreover, TTD had higher scores than ED. Situation complexity also had a significant linear effect on subjective workload (β = .15, p < .01). Post-hoc analyses did not reveal any difference between each situation, except from a marginally significance (t(160) = -1.69, p = .09) with higher scores in very complex situation (M = 12.44, SD = 3.83) than in simple situation (M = 11.01, SD = 3.94).

No other significant effect was obtained for subjective workload (strategies, β = -.02, *ns*; driving experience × situation complexity interaction, β = .02, *ns*; driving experience × strategies interaction, β = -.02, *ns*; and situation complexity × strategies interaction, β = -.07, *ns*).

3.2. Strategies

Participants' strategies were submitted to a 4 (driving experience) × 3 (situation complexity) repeated measures ANOVA. In this model, the adjusted R-squared were 0.23% for the simple situation, -1.12% for the moderately complex situation, and -0.36% for the very complex situation. Driving experience (F (3,110) = 0.21, *n.s*), situation complexity (F (2,220) = 2.13, *ns*) and driving experience × situation complexity interaction (F (6,220) = 1.54, *ns*) did not have any effect on the type of strategies.

3.3. Reaction Times

The mean scores of RT were submitted to a 4 (driving experience) × 3 (situation complexity) × 3 (subjective workload) second order polynomial regression. In this model, all the predictors accounted for 3.20% of the variance (adjusted R-squared). Driving experience significantly shortened the RT (linear effect: $\beta = -.16$, $p < .01$). RTs were thus longer for ETD than for TTD, EPP and ED. Moreover, TTD and ED had longer RT than EPP (see Table 1).

Table 1. Reaction Times of each group.

Driving experience	**Reaction Times, *Mean* (*SD*)**
Traditionally Trained Drivers (TTD)	0.73 (0.26)
Early Trained Drivers (ETD)	0.90 (0.36)
End of Probationary Period (EPP)	0.62 (0.22)
Experienced Drivers (ED)	0.70 (0.30)

The increase of subjective workload significantly shortened the RT with a linear effect ($\beta = -.13$, $p < .05$) and lengthened the RT with a non linear effect ($\beta = .21$, $p < .05$). The driving experience × subjective workload interaction had a significant non linear effect ($\beta = -.21$, $p < .05$). For ETD and EPP, the increase of subjective workload shortened the RTs (respectively $\beta = -.34$, $p < .01$; $\beta = -.22$, $p < .05$), whereas for TTD and ED, the subjective workload did not influence the RTs (respectively $\beta = -.21$, *ns*; $\beta = .07$, *ns*).

No significant effect of situation complexity ($\beta = .05$, *ns*), driving experience × situation complexity interaction ($\beta = -.10$, *ns*), and situation complexity × subjective workload interaction ($\beta = -.08$, *ns*) on RTs was observed.

Sobel tests did not reveal any mediation effect.

3.4. Number of collisions with pedestrians

For the mean number of collisions with pedestrians, a 4 (strategy) × 1 (subjective workload) × 1 (RT) second order polynomial regression was run. In this model, all the predictors accounted for 16.72% of the variance (adjusted R-squared). The increase of subjective workload significantly enhanced the number of collisions (linear effect: $\beta = .12$, $p < .05$). The lengthening of RT increased the number of collisions with a significant linear effect ($\beta = .27$, $p < .001$) whereas it started to slightly increase the number of collisions and finished to decrease the collisions number with a non linear effect ($\beta = -.26$, $p < .01$).

The situation complexity × driving experience interaction had a significant non linear effect on the collisions number ($\beta = -.12$, $p < .05$). For TTD, the number of collisions was higher in very situation than in simple situation. For ED, the scores were higher in simple situation than in moderately complex situation. No other difference was observed (see Table 2).

Table 2. Average number of collisions of each group in each situation.

Driving experience	**Simple, *Mean* (*SD*)**	**Moderate, *Mean* (*SD*)**	**Very complex, *Mean* (*SD*)**
Traditionally Trained Drivers (TTD)	0.07 (0.25)	0.17 (0.38)	0.33 (0.48)
Early Trained Drivers (ETD)	0.25 (0.44)	0.25 (0.44)	0.37 (0.49)
End of Probationary Period (EPP)	0.07 (0.25)	0.17 (0.38)	0.23 (0.43)
Experienced Drivers (ED)	0.03 (0.18)	0.02 (0.41)	0.13 (0.35)

The driving experience × subjective workload interaction significantly influenced the number of collisions (linear effect: $\beta = -.14$, $p < .05$). Indeed, for TTD and ETD, the increase of subjective workload enhanced the number of collisions (respectively $\beta = .22$, $p < .05$; $\beta = .29$, $p < .05$), whereas for EPP and ED, the subjective workload did not influence the number of collisions (respectively $\beta = .08$, *ns*; $\beta = -.08$, *ns*). The situation complexity × strategies interaction significantly influenced the number of collisions (linear effect: $\beta = -.12$, $p < .05$; non linear effect: $\beta = .17$, $p < .05$). In simple situation, the scores were higher for the braking and the combination of braking and swerving than for the swerving. In moderately complex situation, no difference between the strategies was observed. In very complex situation, the scores were higher for the braking than for all the other strategies (see Table 3).

Table 3. Average number of collisions in each situation and for each strategy.

Situation complexity	Braking, *Mean* (*SD*)	Swerving, *Mean* (*SD*)	Combination, *Mean* (*SD*)	Anticipation, *Mean* (*SD*)
Simple	0.18 (0.40)	0 (0)	0.14 (0.35)	0 (0)
Moderately complex	0.12 (0.33)	0.27 (0.46)	0.21 (0.41)	0.14 (0.38)
Very complex	0.54 (0.50)	0.04 (0.21)	0.15 (0.36)	0.17 (0.39)

The subjective workload × strategy interaction had a significant non linear effect on the collisions' number ($\beta = .14$, $p < .05$). For the braking strategy, the increase of subjective workload enhanced the number of collisions ($\beta = .33$, $p < .001$). When the drivers swerved, both braked and swerved, or anticipated, no effect of subjective workload was observed (respectively $\beta = -.04$, *ns*; $\beta = -.15$, *ns*; $\beta = -.25$, *ns*). Finally, the RT × strategy interaction had a significant non linear effect on the collisions' number ($\beta = .14$, $p < .05$). When drivers braked or made a combination, the lengthening of RT increased the number of collisions (respectively $\beta = .33$, $p < .001$; $\beta = .25$, $p < .01$), whereas no effect was observed when they swerved ($\beta = -.13$, *ns*).

The number of collisions was not influenced by strategies ($\beta = .05$, *ns*), situation complexity × subjective workload ($\beta = -.01$, *ns*), driving experience × strategy ($\beta = .05$, *ns*), driving experience × RT ($\beta = -.11$, *ns*), situation complexity × RT ($\beta = -.04$, *ns*), and subjective workload × RT ($\beta = .03$, *ns*).

Sobel tests revealed mediation effects. The effects of situation complexity ($z = 2.13$, $p < .05$) and driving experience ($z = -2.71$, $p < .01$) on collisions number were mediated by subjective workload. The increase of situation complexity and the lack of driving experience enhanced the subjective workload (respectively $\beta = .15$, $p < .01$; $\beta = -.25$, $p < .001$) which in turn increased the number of collisions (respectively $\beta = .17$, $p < .01$; $\beta = .18$, $p < .01$).

4. Discussion

The main purpose of this study was to identify the subjective level of workload produced by situation complexity and driving experience but also to identify the critical level of workload (overload) which produced performance decrement faced with a pedestrian crossing the road in front of the drivers. Three levels of environment complexity and four levels of driving experience were manipulated. The strategies used by the drivers to avoid the pedestrian were analyzed in terms of cost and effectiveness, as a function of situation complexity and driving experience.

As expected, the results showed an effect of situation complexity and driving experience on subjective workload and driving performance. Thus, for all the drivers, an increase of subjective workload was globally observed when the situation complexity increased, with a tendency to higher self-assessment of the workload in very complex situation than in the simple one. The absence of subjective workload difference between the moderately complex situation and the very complex one could be due to a lack of complexity variation, the curves succession probably being too repetitive to modify the perception of the difficulty between these two situations.

Moreover, the lack of experience increased the subjective workload with the highest levels of workload for novice drivers (traditionally trained and early-trained drivers). This increase of subjective workload enhanced the number of collisions with the pedestrians, probably revealing an overload. Therefore, compared to traditionally trained drivers, the additional experience acquired by early-trained drivers did not allow managing a sudden hazard event such as the pedestrian crossing. Conversely, the three-year probation period was sufficient to cope with this event and seems sufficient to acquire a certain level of driving automation, i.e. skill-based behavior (Rasmussen, 1984), which requires less resources to avoid the pedestrians.

As expected and independently of the subjective workload, the number of collisions made by traditionally trained drivers was higher in very complex situation than in the simple one. However, experienced drivers made more collisions in simple situation than in the moderately complex one. This suggests that the subjective workload is not the only factor that could influence driving performance. Indeed, in simple situation (e.g., a monotonous road), low vigilance could not only lead to an increase in errors but to an increase in reaction times as well (Lal, & Craig, 2005). Consequently, the difficulty to avoid the sudden pedestrian appearance was probably enhanced for experienced drivers who drove with a routine automation in a monotonous environment without being flexible. Indeed, routine automation might have produced difficulties to switch from an automatic action to a controlled one which can involve errors (Besnard, & Cacitti, 2001).

Driving experience also had an effect on the reaction times faced with the pedestrians. Indeed, early-trained drivers had longer reaction times than the other groups, and traditionally trained drivers and experienced drivers had longer reaction times than drivers at the end of the probationary period. The results also highlighted that for early-trained drivers and drivers at the end of the probation, the increase of subjective workload shortened their reaction times. This could explain the shortest reaction times of drivers at the end of the probation but not the longest reaction times of early-trained drivers. Another factor might have lengthened early-trained drivers' reaction times, such as the anxiety related to the hazard pedestrian appearance. Indeed, the high temporal pressure to avoid the pedestrian could have provoked a high level of anxiety, often responsible of long reaction times among novice drivers (Wallis, & Horswill, 2007).

Concerning the adopted strategies to avoid the pedestrians, the results revealed no difference between the groups and the situations, probably because none of the strategies was perceived as more costly than another strategy. The strategy adoption was thus not constrained by the felt cost. Consistent with our expectations, several adopted strategies increased the number of collisions as a function of the situation complexity. In simple situation, the number of collisions was higher when the drivers braked and made a combination than when they swerved. According to Adams (1994), this result confirms that the swerving strategy was more effective than the braking one. But, contrary to the statement of Adams (1994), the combination strategy was not more effective than the braking one, and we noted that the anticipation strategy did not lead to fewer collisions. These results could be due to the high monotony of the simple situation which could decrease the level of vigilance, leading to specific difficulties to effectively combine two actions in a short time or to prevent the drivers from rapidly conducting their avoidance maneuver despite the early setting up of an action.

In very complex situation, the number of collisions was higher when drivers braked than when they made a combination of braking and swerving, or when they swerved or anticipated. These three avoidance maneuvers were thus the most effective strategies. The high complexity probably allowed the drivers being vigilant and prepared them to adopt the most effective strategies (Adams, 1994).

Additionally, the increase of subjective workload only enhanced the number of collisions when the drivers braked, confirming that the braking strategy did not prevent colliding with the pedestrian. Furthermore, whatever the situation and the driving experience, braking or making a combination was not effective when the reaction times were lengthened, as the number of collisions increased. Conversely, swerving was always effective, even with the lengthening of reaction times (constant number of collisions).

To conclude about the strategies, they did not vary between the situations and the groups and had an equivalent cost. However, this study reveals that whatever the situation complexity and the driving experience, the swerving strategy was the most effective to avoid an accident with a sudden pedestrian crossing, even when drivers' reaction times were long. Further research is needed to confirm a possible link between the level of vigilance due to the situation complexity and the strategy effectiveness.

Finally, all the results revealed that, in these experimental conditions, the subjective workload was depending on driving experience and situation complexity and determined reaction times for early-trained drivers and drivers at the end of the probation. Moreover, the number of collisions was depending on subjective workload, avoidance strategies and reaction times, and this link was modulated by situation complexity as a function of driving experience (see Fig 3).

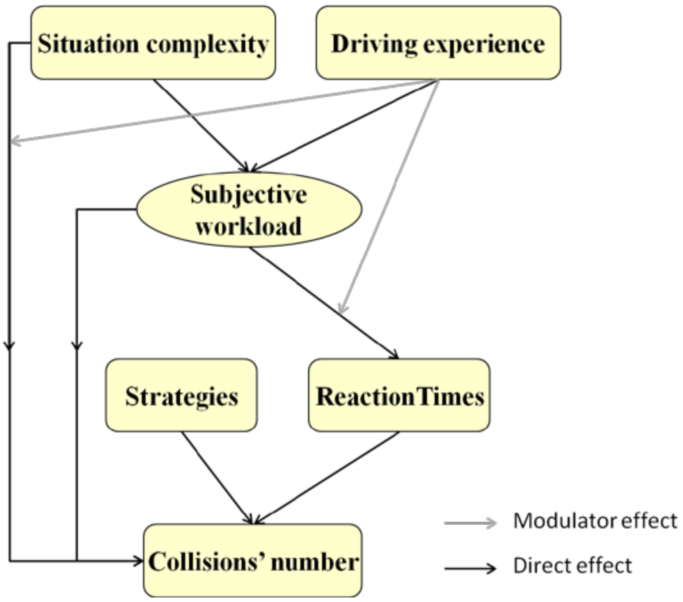

Fig 3. Predictors of the collisions' number.

Therefore, only considering driving characteristics (performance) and environment characteristics (complexity) is not sufficient to explain and to understand driving situations. Taking the individual characteristics into account seems essential and will permit to implement preventions targeted to individuals.

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