Development of Children's Crossing Skills in Urban Area: Visual Exploration and Mental Representation about Hazards

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***Abstract*—Pedestrian trauma represents a significant proportion of all road traumas, young pedestrian being over-represented in all these road traumas. From a cognitive point of view, road crossing ability is a high and complex mental activity because the individual has to process dynamic and complex information extracted from his/her surrounding environment, to make a decision (i.e., where and how to cross), and safe pedestrians must possess and utilize advanced cognitive skills. More precisely, there are two major problems for young pedestrians to make the decision about when and where it is safe to cross the street: gap selection and assessment of inter-vehicular gap. A first study conducted with forty children aged 3-10 years and twenty-two adults has been conducted to investigate the impact of one individual factor (Age) and one environmental factor (Traffic density) on decision making (i.e., "to cross" or "not to cross a street"), time spent to make decision (in milliseconds) and on visual exploration using eye-tracking techniques of urban scenes displayed on a computerized screen. Main results showed that (i) Traffic density has a significant impact on performance and visual exploration, (ii) Age has a significant impact on time spent to make decision and visual exploration and (iii) there is an interaction between Age and Traffic density. A second study, based on drawings performed by 125 young pedestrian provided relevant qualitative and subjective data to complete data issued from the first experiment based on eye-tracking technique. The children's drawings are more elaborate and richer (in terms of the number of elements represented) as the real accident risk in their environment increases. Not only does the number of elements in the drawings increase quantitatively, but these elements are more closely linked to each other, to the point where they form a real scene. The mental representation becomes more and more precise, and the egocentric perspective is dominant, this result being consistent with the Piagetian approach to the development of intelligence for children.**

***Keywords*—Child; Pedestrian; Visual exploration; Risk; Hazard; Eye-Tracking; Drawing; Perceived risks**

I. INTRODUCTION

Because pedestrian trauma represents a significant proportion of all road traumas, and because young pedestrian being over-represented in all these road traumas [1], the safety of child pedestrians is of concern, given that a sizable proportion of pedestrians killed and seriously injured involve children and the special value society places on its youth [2][3]. Although there is no consensus definition, most data sets identify pedestrians as those walking, running, standing, or lying on a road, right of way, or parking lot [4][5] and people on bicycles, skateboards, and other non-powered conveyances are not considered pedestrians for the purposes of this report. Pedestrian injury data are often stratified into "traffic" data, which include those injured or killed while on the roadway, and "non-traffic" data involving those struck on driveways or private lots, an important subset of the injured among younger children

The structure of this paper is the following:

- In Section I, context and challenges related to accidents with young pedestrians and factors influencing children's crossing skills are presented;
- In Section II, two studies conducted with our participants are described: The first study is based on eye-tracking data issued from an experiment conducted with children aged 3-10 years-old to investigate the impact of several specific factors on gaze exploration and decision-making; The second study is based on analyses of drawings performed by young pedestrians. In other words, the first data are quantitative while the data extracted from drawings are more subjective;
- Finally, in Section III, theoretical and methodological implications related to the changes in visual strategy occurring around the age of 7-8 years are discussed.

A. Context

Around the world, the number of pedestrians killed increases. Young pedestrians are particularly concerned by these accidents: According to the official data issued from the Traffic Safety Facts, on average, three children were killed and an estimated 502 children were injured every day in the U.S. in traffic crashes. In 2019 and 2020, there were respectively 181 and 177 children killed in pedestrian accidents. Most were toddlers (between the ages of 1-3) and young children (4-7). In fact, an estimated 1 in 5 children killed in car accidents were pedestrians, i.e., just walking on the sidewalk or crossing a street whatever the country [6][7].

At ages 6-10 years, children are at highest risk of pedestrian collision, most likely due to the beginning of independent unsupervised travel at a time when their road strategies, skills and understanding are not yet fully developed [8]. Whatever the country, research suggests that children between the ages of 6 to 10 are at highest risk of death and injury, with an estimated minimum four times the risk of collision compared to adult pedestrians [9]. Until the age of 6-7 years, children are under active adult supervision, i.e., parents hold their child's hand when crossing roads together.

Even if every year many pedestrians are injured or killed in traffic accidents in rural parts of the country [10], pedestrian safety is being considered as a serious traffic safety problem in urban and suburban settings [11][12]. Thus, children more than adults, are at risk as pedestrians, often due to their own actions and behaviors. So the question is: "Why do young pedestrians not adopt safety behaviors specially during street crossing?"

B. Factors Influencing Children's Crossing Skills and Gap Selection

From a cognitive point of view, road crossing ability is a high and complex mental activity because the individual has to process dynamic and complex information from his/her surrounding environment, to make a decision (i.e., where and how to cross). Safe pedestrians must possess and utilize advanced cognitive skills [13][14]. Crossing decisions include whether or not to enter the roadway, the place to cross, the path to take, how fast to travel, and how the driver might react. A sound decision on whether to enter the roadway should be based upon recall (experience) and monitoring of the traffic detected, including the distance, speed, and anticipated direction of vehicles and the opportunities provided by various gaps in traffic [15]. The time that has elapsed while making the decision also needs to be incorporated. Successful crossing performance also requires reliable estimation of the pedestrian's walking speed, peak capabilities, and distance to the other side of the road or a traffic island. Integrating all these aspects is difficult for the child, especially one inexperienced in traffic, and result in a longer decision making time: In fact, a 5 year old child requires about twice as long to reach a pedestrian decision as an adult, and this leaves even less time to execute an imperfectly planned crossing [13][14][16].

A vast amount of research suggests that children's development of cognitive skills is significantly related to increased pedestrian safety and that relevant skills improve as children get older [17][18][19]. Of course, it is not a single cognitive skill that influences safety. Instead, it is the combined development of a number of different cognitive processes that are linked to safe pedestrian behavior. Those processes also overlap with other developing skills, such as perceptual (visual and auditory essentially) and motor abilities.

As children develop, specific pedestrian injury risks change [16][19][20][21][22][23]. More precisely, toddlers (ages 1–2) are most likely to be injured in driveways, where drivers moving backward are unable to see them [24], while adolescents are at risk due to walking at night with poor visibility, walking while intoxicated or walking while distracted by phones [25]. Our paper focuses on children between those two phases, in ages 6 through 12. During this stage of development, most pedestrian injuries occur in mid-block areas, where children enter into the middle of the street and are struck by moving vehicles, or at intersections [26]. As Schwebel and his colleagues said, if some incidents are "dart-out" situations where children enter the street quickly, without thought (i.e., to chase a person, toy, or pet, or to meet someone on the other side of the street), the majority of the incidents/collisions are the result of poor judgment by the child, i.e., s/he believes it to be safe, and enters the street when in fact the situation is not safe [23].

Several studies showed that gap selection and assessment of inter-vehicular gap by young pedestrians are two major problems for young pedestrians to make the decision about when and where it is safe to cross the road [27][28][29]. Inter-vehicular gap is both temporal and spatial because these two parameters are crucial to make the decision in relation to available gaps in the traffic [30]. More precisely, judgement of whether a gap in the traffic is sufficient to safely cross requires the determination of the time gap of the nearest vehicle with the planned crossing line and the assessment of whether this time gap exceeds the time required to cross the road. So, children aged below 10 years have relatively poor skills at reliably setting safe distance gap thresholds, and thus do not consistently make safe crossing decisions [31][32][33][34][35][36].

But, very few authors concentrated on visual exploration of young pedestrians during crossing activity. For instance, Whitebread and her colleagues examined the relationships between pedestrian skills and visual search strategies for young pedestrians [37]. According to their findings, major changes in strategy occurred around the age of 7-8 years. This change expressed in the frequency and pattern of looking at different directions, having a sophisticated 'last-minute' checking approach, exhaustive visual search strategy, and the speed of making the crossing decision. In the same way, Tapiro and her colleagues examined children's visual search strategies in hazardous road-crossing situations [33]. A sample of 33 young participants (ages 7-13) and 21 adults observed 18 different road-crossing scenarios in a 180 degrees dome shaped mixed reality simulator. Gaze data were collected while participants made the crossing decisions. Their results showed that age group, limited field of view, and the presence of moving vehicles affect significantly the way pedestrians allocate their attention in the scene. Therefore, the authors hypothesized that adults tend to spend relatively more time in further peripheral areas of interest than younger pedestrians do. It was also found that the oldest child age group (11-13 years old) demonstrated more resemblance to the adults in their visual scanning strategy, which can indicate a learning process that originates from gaining experience and maturation. Nevertheless, all participants in these previous studies were 7 years old and above. In our experiment, we collected data with eye-tracking from younger pedestrians (3 to 10 years old) to better understand the visual exploration of urban scenes.

II. Experiment 1: Visual exploration before to cross a street

This experimental study conducted with forty children aged 3-10 years and twenty-two adults was aiming to investigate the impact of one individual factor (Age) and one environmental factor (Traffic density) on decision making (i.e., "to cross" or "not to cross a street"), time spent to make decision (in milliseconds) and on visual exploration of urban scenes displayed on a computerized screen. Eye-tracking technique is used to collect precise data about gaze exploration of each participant.

A. Participants

Sixty-two French participants were recruited to participate in this study. Children are issued from four different age groups: Seven pupils are from Grade 1 (boys, 100 percent; mean age = 3.86 years; SD = 0.37 years), nineteen pupils are recruited from Grade 3 (boys, 56.8 percent; mean age = 6.89 years; SD = 0.31 years), fifteen pupils are recruited from Grade 5 (boys, 60 percent; mean age = 9.87 years; SD = 0.51 years), and twenty-one participants are adults (men, 47.6 percent; mean age = 26.71 years; SD = 8.22 years). All children are issued in the same elementary school located in the mid-town.

All participants are French native speakers and the majority (82.1 percents) lives in urban area. Moreover, even if the majority of adult participants (81 percents) have their driving license, they admit to go to work essentially by using public transportation (61.9 percents) or by walk (38.1 percents). All the children are recruited in the same primary school located in the mid-town. All parents agreed to their children participate. No participant has severe visual impairment and no cognitive impairment. There is no difference between groups according to the visual memory and attention capacities (Table I).

B. Independent and Dependent Variables

In our study, we investigated the impact of one individual factor (Age) and one environmental factor (Traffic density) on three behavioural indicators:

- The decision (i.e., "to cross" versus "not to cross the street");
- The time spent in milliseconds to make this decision;
- The visual exploration of specific Areas of Interest (AoI) of urban scenes displayed on pictures (Figure 1);

Thus, two independent factors were manipulated, the first one being intra-subject ("Age", with four modalities: Grade 1, Grade 3, Grade 5, and adults) and the second one being inter-subject ("Traffic density", with three modalities: Low, Moderate, and High). In other words, our experimental plan was: Participant $<$ Age 4 $>$ * Traffic density 3.

C. Material

Assessment of Cognitive Abilities. Each participant was asked to complete several sub-scales extracted from the Wechsler scales to assess their cognitive abilities. For the youngest participants (Grade 1), "Coding scale" and "Digit span scale" extracted from the WPPSI-V have been used. For the two other groups of children (Grade 3 and Grade 5), they are the same sub-tests used but extracted from the WISC-V. For adults, four sub-scales extracted from the WAIS-V have been used: "Digit span scale", "Arithmetic scale", "Coding scale", and "Symbol scale". All these sub-scales were chosen because they are very sensitive to the visual memory and attention capacities.

Urban Scenes. Each participant was individually asked to examine different urban scenes displayed on a computerized screen before to make a decision for each urban scene, i.e., "to cross" or "not to cross the street". Three traffic densities have been used to investigate the impact of this factor on decision-making and visual exploration: Low, Moderate, and High. Figure 1 shows an example for each of these modalities. For each of the traffic density (Low, Moderate, and High), four different urban scenes. These urban scenes were chosen by four judges after they evaluated and categorized a lot of pictures in these three traffic conditions: Low traffic density ("Low"; e.g., one other pedestrian and two vehicles far), moderate traffic density ("Moderate"; e.g., several other pedestrians and different kinds of vehicles), and high traffic density ("High"; e.g., a lot of vehicles near and far).

Each participant was asked to examine 12 different static pictures of urban scenes, the order of presentation being counterbalanced to avoid order effect on responses (i.e., "to cross" or "not to cross the street"). On-line eye-tracking data for each participant were collected during participants examined urban scenes, by using the eye-tracking techniques. The Tobii T120, with a 17 inch monitor integrated, was used to collect visual exploration of urban scenes by our participants.

D. Procedure

The procedure has four distinct and successive steps:

- Training session. First, each participant was invited to seat in front of a computer (Tobii T120, with a 17 inch monitor integrated) and the same instructions are given: (a) different images will appear on the screen, one by one; (b) s/he must to analyse the urban scenes carefully because s/he was asked to decide if s/he crosses or not the street; (c) when s/he made the decision, s/he was asked to say "stop" and s/he can give his/her decision orally.

TABLE I
MEAN (AND STANDARD DEVIATION) OF FIXATION DURATION FOR EACH AGE GROUP, TRAFFIC CONDITION FOR EACH AREAS OF INTERESTS (AOI)

	Mean of Memory Span (SD)	Mean of Processing Speed (SD)
Grade 1 ($n = 7$)	8.5 (2.7)	9.5 (3.4)
Grade 3 ($n = 19$)	10.5 (4.5)	12.8 (5.1)
Grade 5 ($n = 15$)	10.9 (2.9)	10.2 (3.9)
Adult ($n = 21$)	9.1 (1.9)	10.6 (2.8)

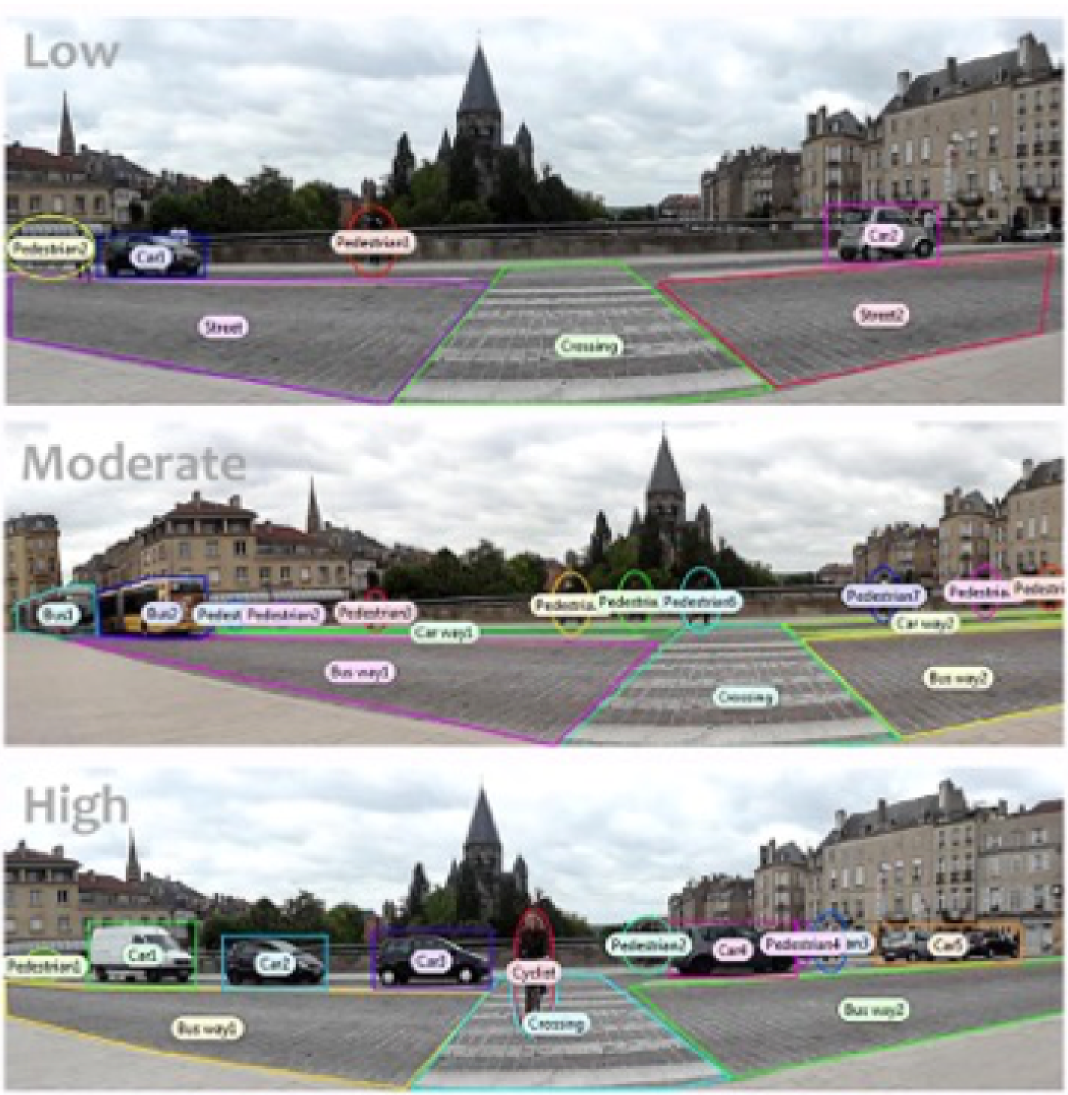

Figure 1. The different Areas of Interest (AoI) in the three Traffic density conditions

Different pictures (not used in the following experiment) are used during a training session;

- Experimental session for visual exploration and decision-making. If the participant has no problem with the procedure and has no question, the experiment can begin with the urban scenes related to the three conditions (Low, Moderate, High);
- Assessment of cognitive abilities. Just after the end of the experimental session, each participant was asked to complete sub-scales extracted from the Wechsler scales to assess their visual memory and attention capacities;
- Length of time the subject is expected to participate
- Researchers ensured that those participating in research will not be caused distress;
- End of the experiment. Finally, each participant was asked to complete a survey to provide some several demographic information, is thanked and each child receives a packet of sweets.

Note that for children, the experiment was always conducted in the same quiet room located in the school, dedicated to the experiment. The experimenter was always the same.

E. Design and Data Analysis

First, we examined the impact of our two independent variables ("Group age" and "Traffic condition") on the one hand, decision (i.e., "I am crossing" or "I am not crossing"), and on the other hand, time spent to make this decision (in milliseconds). So the design of this first part of analyses is the following factorial design: Group age (4) (Grade 1, Grade 3, Grade 5, Adult) X Traffic density (3) (Low, Moderate, High), with "Age group" as between-subjects factor and "Traffic density" as within-subjects factor.

Second, we examined the visual exploration on specific Areas of Interest (AoI) predefined for urban scenes (i.e., "Pedestrians", "Sidewalk", "Car", "Car way", Bus", "Bus way", and "Crossing"). Figure 1 shows these six different AoI. The design of this second part of analyses is the following factorial design: Age group (4) (Grade 1, Grade 3, Grade 5, Adult) X Traffic density (3) (Low, Moderate, High) X AoI (6) (Pedestrians, Sidewalk, Car, Car way, Bus", Bus way, Crossing) with "Age group" as between-subjects factor and "Traffic density" and "AoI" as within-subjects factors.

F. Ethics

All adults' participants provided written informed consent for their participation in this study, and all legal parents of children provided the same informed consent. Moreover, the responsible of the school provided also her consent. Before providing the written consent, all adults' participants, legal parents of children and the director of the school where the research has been conducted received the same information relating to the following points:

- A statement that participation is voluntary and that refusal to participate will not result in any consequences or any loss of benefits that the person is otherwise entitled to receive;
- The precise purpose of the research;
- The procedure and material involved in the research;
- Benefits of the research to society and possibly to the individual human subject;
- Length of time the subject is expected to participate
- Researchers ensured that those participating in research will not be caused distress;
- Subjects' right to confidentiality and the right to withdraw from the study at any time without any consequences;
- After the research is over, each participant (adults or children) are able to discuss the procedure and the findings with the psychologist.

G. Main Results

The experiment based on eye-tracking techniques aimed to investigate the impact of one individual factor (Age) and one environmental factor (Traffic density) on three behavioural indicators related to competencies of very young pedestrians (aged 3-10 years). Several interesting results have been obtained.

The decision made by each participant ("I cross" versus "I do not cross") in front of each urban scene has been collected (Table II). For each if the three Traffic density conditions (Low, Moderate, High), statistical analyses revealed only one significant impact of Age group in high traffic condition ($F(3\text{-}58) = 2.858$, $p = .045$).

As Table III shows, the time spent to make decision decreased with age. Statistical analyses confirmed that Age group had a significant impact on this time spent to make decision ($F(3\text{-}58) = 8.75$, $p < .001$). Time spent to make decision for the youngest participants (Grade 1, Mean = 8829.68) was superior than time spent by all the other participants (Grade 3, M = 5240.98, $F(3\text{-}58) = 2.934$, $p = .005$; Grade 5, Mean = 4694.68, $F(3\text{-}58) = 3.265$, $p < .005$; Adults, Mean = 2797.82, $F(3\text{-}58) = 4.996$, $p < .001$). In the same way, time spent to make decision for participants aged to 6-7 years (Grade 3, Mean = 5240.98) was superior than time spent for adults (Mean = 2797.82), the difference being significant ($F(3\text{-}58) = 2.789$, $p = .007$). Finally, time spent to make decision for participants in grade 5 (Mean = 4694.68) was superior than time spent adults (Mean = 2797.82), the difference being significant ($F(3\text{-}58) = 2.028$, $p = .047$) Traffic condition had also a significant impact on time spent to make decision ($F(2\text{-}116) = 7.67$, $p = .001$). As Table II shows, time spent to make decision in low traffic condition (Mean = 4311.31) was inferior than time spent in high traffic condition (Mean = 5278.16), the difference being significant ($F(2\text{-}116) = 7.67$, $p = .002$). Finally, there was a interaction between Age group and Traffic condition ($F(6\text{-}116) = 2.73$, $p = .016$) on the time spent to make a decision.

There was a global impact of Age group on total fixation duration (Table IV; $F(3\text{-}58) = 8.475$, $p < .001$). Specifically, Age group had a significant impact for Low traffic density ($F(3\text{-}56) = 2.980$, $p = .039$) and Moderate traffic density ($F(3\text{-}56) = 9.422$, $p = .001$) but had no impact on High traffic density ($F(3\text{-}50) = 2.695$, $p < .056$):

TABLE II
NUMBER (AND PERCENTAGE) OF PEDESTRIANS CROSSING THE STREET FOR EACH AGE GROUP AND THE THREE TRAFFIC DENSITY CONDITIONS (LOW, MODERATE, HIGH)

	Low	Moderate	High
Grade 1 ($n = 7$)	3 (42.8)	2 (28.5)	1 (14.9)
Grade 2 ($n = 19$)	12 (63.6)	2 (10.5)	0 (-)
Grade 2 ($n = 15$)	10 (66.6)	3 (20)	3 (20)
Adult ($n = 21$)	9 (42.8)	3 (14.2)	5 (23.8)

TABLE III
MEAN (AND STANDARD DEVIATION) OF TIME SPENT TO MAKE DECISION (I.E., "TO CROSS" *versus* "NOT TO CROSS") FOR EACH AGE GROUP AND EACH TRAFFIC DENSITY CONDITION (LOW, MODERATE, HIGH)

	Low	Moderate	High	Mean (SD)
Grade 1 ($n = 7$)	7854 (6399)	7183 (5081)	11450 (10673)	8829 (6812)
Grade 3 ($n = 19$)	4921 (2292)	5337 (1803)	5464 (3140)	5240 (2030)
Grade 5 ($n = 15$)	3804 (1616)	4454 (2175)	5825 (3902)	4694 (1981)
Adult ($n = 21$)	2940 (1708)	2791 (1245)	2661 (1592)	2797 (1345)
Total mean (SD) (N = 62)	4311 (3066)	4469 (2672)	5278 (5025)	-

TABLE IV
MEAN (AND STANDARD DEVIATION) OF TOTAL FIXATION DURATION FOR EACH AGE GROUP AND THE THREE TRAFFIC DENSITY CONDITIONS (LOW, MODERATE, HIGH)

	Low	Moderate	High	Mean (SD)
Grade 1 ($n = 7$)	0.316 (0.08)	0.362 (0.06)	0.408 (0.124)	0.379 (0.09)
Grade 2 ($n = 19$)	0.351 (0.145)	0.357 (0.10)	0.321 (0.14)	0.343 (0.13)
Grade 5 ($n = 15$)	0.303 (0.07)	0.266 (0.06)	0.267 (0.12)	0.265 (0.08)
Adult ($n = 21$)	0.266 (0.05)	0.290 (0.04)	0.278 (0.04)	0.297 (0.06)
Total mean (SD) (N = 62)	0.320 (0.09)	0.311 (0.07)	0.318 (0.11)	-

- For Low traffic density condition, mean fixation duration for children recruited in Grade 1 was higher compared to Adults (respectively, Mean = 0.3614 and Mean = 0.2665; t(56) = 2.183, p = .033). In the same way, children recruited in Grade 3 have more longer fixation duration compared to Adults (respectively, Mean = 0.3514 and Mean = 0.2665; t(56) = 2.639, p = .011). Adults had the fastest fixings but that was significant only that in comparison with Grade 1 and Grade 3;
- For Moderate traffic density condition, adults (M = 0.29) had shorter fixation duration compared to Grade 1 (respectively, Mean = 0.29 and Mean = 0.3692; t(56) = 2.293, p = .026) and compared to Grade 3 (Mean = 0.3579; t(56) = 2.656, p = .01). Children issued from Grade 5 spent significantly less time to make decision than Grade 1 (Mean = 0.3692; t(56) = 3.950, p = .000), compared to Grade 3 (Mean = 0.3579) (t(56) = 4.76, p = .000) and compared to adults (Mean = 0.29) (t(56) = -2.345, p = .023);
- For High traffic density condition, only one Age group was concerned by significant differences: Children issued from Grade 1 spent significantly more time to make decision compared to Grade 5, compared to Grade 1 (respectively, Mean = 0.4081 and Mean = 0.2673; t(50) = 2.521, p = .015) and compared to Adults (Mean = 0.05893; t (50) = 2.54, p = .014). In other words, in the high traffic density condition, children issued from Grade 1 were the slowest.

As Figure 2 shows, visual fixation duration time was significantly superior for two of the different Areas of Interest (AoI) predefined: the car way (F(3-43) = 4.191, p = .011) and the crossing (F(3-55) = 3.891, p = .014).

Moreover, Age group had a significant impact on distribution of fixation time only for these two of the different Ares of Interest (AoI) predefined. Fixation duration time on the car way was superior for Grade 1 compared to Grade 5 (respectively, Mean = 0.3625 and Mean = 0.2444; t(43) = 2.426, p = .02) and compared to Adults (Mean = 0.2311; t(43) = 2.626, p = .012). And fixation duration time on the car way was superior for Grade 3 compared to Grade 5 (respectively, Mean = 0.3291 and Mean = 0.2444; t(43) = 2.329, p = .025) and compared to Adults (Mean = 0.2311; t(43) = 2.569, p = .014).

The pattern of results was identical for the crossing. Fixation duration time on the car way was superior for Grade 1 compared to Grade 5 (respectively, Mean = 0.3729 and Mean = 0.2713; t(55) = 2.3, p = .025) and compared to Adults (Mean = 0.2478; t(55) = 2.932, p = .005). And fixation duration time on the car way was superior for Grade 3 compared to Adults 5 (respectively, Mean = 0.3248 and Mean = 0.2444; t(55) = 2.425, p = .019).

Even if there were the only significant differences, some interesting tendencies can be remarked in the Figure 2 for other AoI such as "Pedestrians", "Cars" and "Bus way". For these three other AoI, fixation duration time for Adults group is always inferior.

There exist some significant interactions between Age group and Traffic density condition on these fixation duration means for the two main AoI ("Car way" and "Crossing"):

- For Low traffic density condition, fixation duration for younger participants (recruited in Grade 1) was significantly superior than fixation duration for children recruited in Grade 3 specially for "Car way" (respectively, Mean = 0.45 and Mean = 0.263; t(54) = 2.023, p = .048);
- In the same way, for Moderate traffic density condition, fixation duration for younger participants (recruited in Grade 1) was also significantly superior than fixation duration for children recruited in Grade 3 (respectively, Mean = 0.768 and Mean = 0.438; t(55) = 3.218, p = .002);
- Finally, for High density traffic condition, fixation duration for children issued from Grade 1 was also superior than fixation duration specially for "cars" (respectively, Mean = 0.430 and Mean = 0.290; t(56) = 2.019, p = .048). The crossing site was extensively explored by the youngest participants (Grade 1, Mean = 0.442) compared to Adults (Mean = 0.229; (t(50) = 2.413, p = .020) and compared to children recruited in Grade 5 (Mean = 0.374; (t(50) = 2.857, p = .006).

Several interesting results have been obtained in this first experiment. The Traffic density has a significant impact on decision made by all the participants. When there is much information in the urban scene (High traffic condition), less participants decide to cross the street, whatever the Age. Second, the Age has a significant impact on time spent to make decision. The decision-making time decreases when the age increases. This result confirms the fact that the age has a strong impact on decision making in pedestrians' skills a process which develops and becomes increasingly effective with the age [38][39][40]. Third, there is an interaction between Age and Traffic density: The decision-making time decreases when the age increases specially when there is much information in the urban scene (i.e., High traffic density condition). In a second experiment, we investigated more precisely mental representations of children about hazards in their surrounding physical environments by analyzing drawings performed by these children.

III. Experiment 2: Mental representations of children about the risks in the streets

Children's drawings can function as a fascinating window into how kids perceive and represent their world [41]. They are also helpful tools for researchers, because young children sometimes find it easier to communicate with imagery rather than words. Through the process of observing and analyzing the drawings of young children, insights can be gained as to the social/emotional, physical, and intellectual development of each child. Children usually explore the world around them through intellectual, physical and emotional methods for young children; pencil, brush and paper are the best means of conveying their perception of their surrounding environment.

The progression of drawings performed by children can show significant growth and development, as well as determine academic capabilities and skills characteristic of their developmental level [42][43]. For instance, the ability to localize an object with an allocentric or object-centered perspective [44][45], based on reference points external to the body and develops later, when the child becomes conscious of object permanence in space, regardless of the child's position, is easy to identify in drawings (Figure 5, [45]).

A. Participants

One hundred and twenty-five children agreed to take part in this study. The participants were distributed as follows: 20 children attended a school located in a high-risk zone (7 boys and 13 girls; mean age = 7.6 years, SD = 0.5); 76 children attended a school located in a moderate-risk zone (36 boys and 40 girls; mean age = 7.38 years, SD = 0.67); finally, 29 children attended a school located in a low-risk zone (17 boys and 12 girls; mean age = 7.41 years, SD = 1.05).

The distinction between the three types of zone according to risk (low, moderate, high) was made on the basis of accident data compiled by the Metz Urban Community: The first school is located in the city's hyper-centre, in a historic district, where road traffic is heavy and previous accidents (i.e., pedestrian-vehicle collisions) confirm that the risk is high. The second establishment is also in the city centre, but in a semi-pedestrian area. There have been few previous accidents, so the road risk is considered moderate. Finally, the last establishment is located on the outskirts of the city centre, in a residential area with little traffic, and the number of previous accidents is virtually nil: the risk is therefore low.

B. Protocol and Design

In order to question children about their perceived risk when they navigate in town, we decided to ask them to draw a picture with the following instructions: "The Little Pedestrian is going to take part in the 'Pedestrian Challenge' with you. Can you draw the things s/he needs to watch out for and the things that could be dangerous for him/her?"

The 'Pedestrian Challenge' is an event organised by the city of Metz every year. It is open to all pupils in Grade 2 and Grade 3, i.e., several hundred children aged between 6 years-old and 8 years-old. The event consists of a life-size

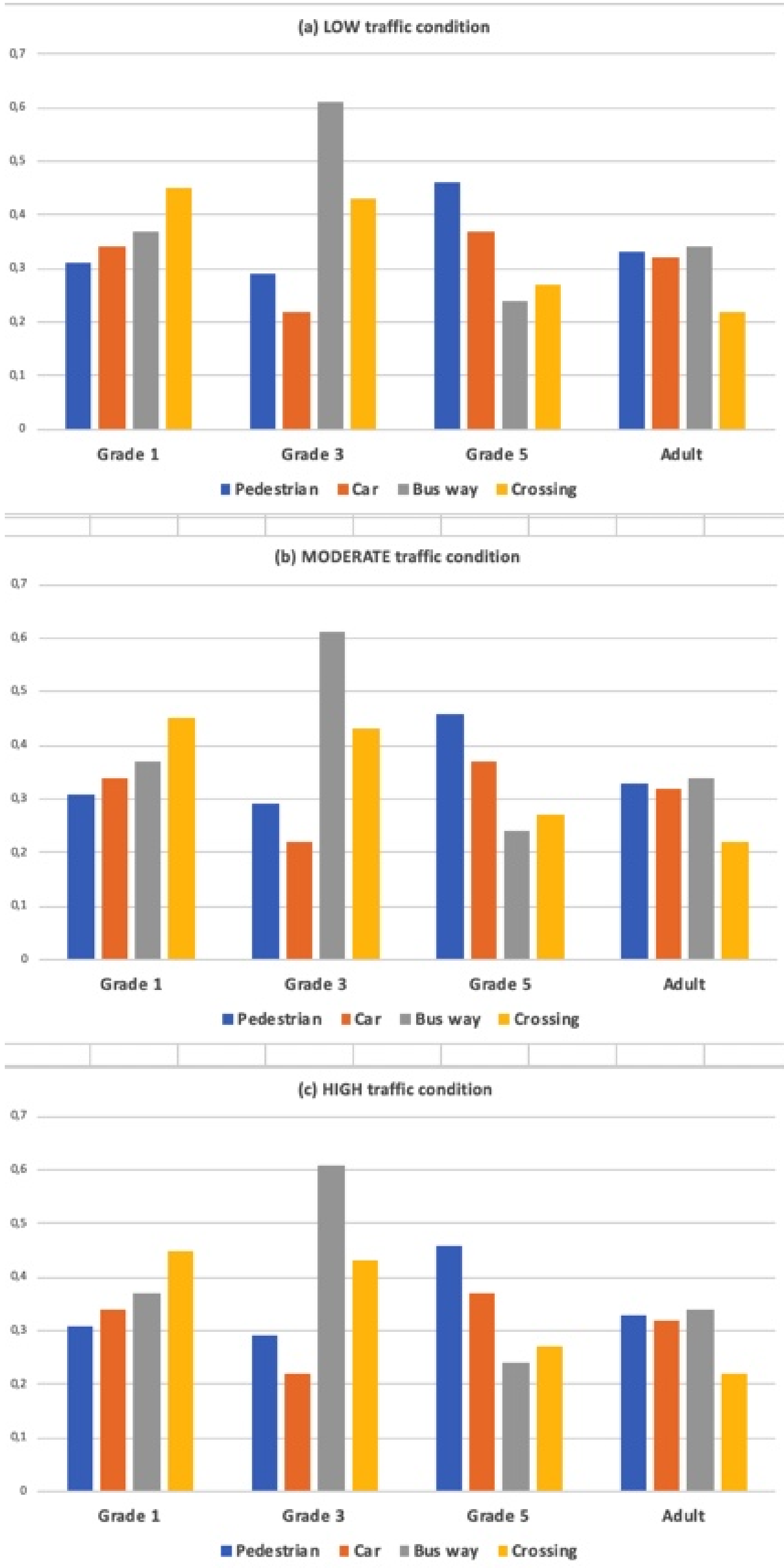

Figure 2. Mean of visual fixation duration for each Age Group (Grade 1, Grade 3, Grade 5, Adult), Traffic Condition (LOW / MODERATE / HIGH) for each Areas of Interests (AOI : Pedestrian / Car / Bus way / Crossing)

simulation of pedestrian navigation throughout the city. Pupils from Metz schools navigate independently along a predefined route through the city, confronting them with key pedestrian navigation situations (e.g., crossing several carriageways, bus lanes, cycle paths, complying with road safety rules, leaving car parks).

This individual task was carried out in the pupils' classrooms during their school time, in order to preserve a familiar context. Each child was given 15 minutes to draw his or her picture, during which time the experimenter collected verbalizations.

C. Analysis of drawings

In this study, we decided to take an objective quantitative approach to the qualitative material represented by these drawings. An ad hoc observation grid was therefore developed. The aim was to make a rigorous inventory of all the elements making up the drawings. The approach consists of adding each new element to the observation grid; the elements are then sorted and grouped into categories. The categories in the observation grid are characterised by their discriminating power and their exclusivity (an element cannot belong to several categories at the same time). Some categories are created to list elements that cannot be precisely identified or are irrelevant (e.g., the "decorative" category includes all decorative elements).

The observation grid developed to analyse the drawings produced by the 125 children ultimately comprised 7 categories:

- the point of view adopted by the child to produce the drawing (i.e., allocentric or egocentric orientation of the drawing [46]);
- decorative elements (trees, flowers, etc.);
- textual/language elements (e.g., instructions, first names, onomatopoeia);
- characters (male vs. female, and child vs. adult);
- traffic lanes (for car, pedestrian, bus, bike);
- signs (traffic lights for pedestrian, lights for bus, stop sign, crossing sign, pedestrian crossing);
- vehicles (car, bus, lorry, ambulance, fire engine, police vehicle, bicycle and other unidentifiable vehicles); For each of the items in each of the seven categories, the presence in each drawing produced was counted by distinguishing the objective accident risk in which each child is involved (low, moderate, high risk).

D. Main Results

With regard to the point of view adopted by the child in making the drawing (i.e., allocentric vs. egocentric drawing orientation), the egocentric perspective is in the majority. Figures 3 and 4 show two examples of drawings in these two categories. Between 60.53% and 90% of the drawings are produced from an egocentric point of view. The egocentric view is a 'first person' representation of the scene seen through the eyes of the author of the drawing. In other words, the elements represented in the egocentric drawing are drawn in the way they are actually perceived/seen by the children. In contrast, the allocentric view, which concerns only a minority of the drawings, can be described as a 'bird's eye view'. In other words, it is a general view of the scene, as on a map, which enables the elements and the spatial links between them (e.g., distance, orientation, arrangement) to be identified.

Taking all categories of elements together, the average number of elements present in the drawings increases with the objective accident risk: drawings produced by children attending schools located in low-risk areas contain an average of 7.07 elements (SD = 2.90); those produced by children attending schools in moderate-risk areas have an average of 8.45 elements (SD = 3.17); finally, the drawings produced by children attending schools in high-risk areas have an average of 9.35 elements (SD = 3.17). The difference was significant only between low- and high-risk areas ($t(48) = 8.65$, $p=.001$). In any case, the richness of the drawings in terms of the number of elements present increases with the actual accident risk.

There were very few decorative elements in the drawings (e.g., trees, flowers, buildings). This relatively low proportion can certainly be explained by the time given to the children to produce their drawings (15 minutes). The textual and/or linguistic elements added to the drawings by the children were of two distinct types: some corresponded to material that children usually find in comics and children's literature (e.g., greetings, first names, dialogue in speech bubbles, onomatopoeia); the majority corresponded to instructions (e.g., "Look carefully to the left and right"). We note that none of the drawings produced by children attending schools in low-risk areas contain any textual elements. On the other hand, these textual/language additions were more frequent in the drawings produced by children attending schools in moderate (30.26%) and high (25%) risk areas.

The difference was significant only between low-risk areas and moderate- and high-risk areas (respectively: $t(95) = 19.26$, $p=.001$; $t(48) = 13.84$, $p=.001$). In other words, explicit instructions relating to urban navigation are more often present in the drawings produced by children attending school in areas of moderate or high accident risk.

As far as the characters are concerned, the drawings are very different depending on the schools where the children attend. In fact, only 13.79% of the drawings produced in low-risk areas include characters. Conversely, characters become a recurring feature in moderate-risk conditions (39.47%), and are very often present in high-risk conditions (65%). In the latter two cases, the drawings mainly represent scenes, most often a road crossing. The character is often of the same gender as the child producing the drawing (mechanism of identification and projection into the scene). The child then depicts himself alone or accompanied by her/his peers. The adults depicted are most often an instructor (a teacher?) or at least an adult performing traffic control and/or supervisory functions (presence of the "high visibility" jersey worn by security guards on the public highway). We can see that, although the instructions initially given to the pupils were intended to draw their attention to the vehicles, their drawings

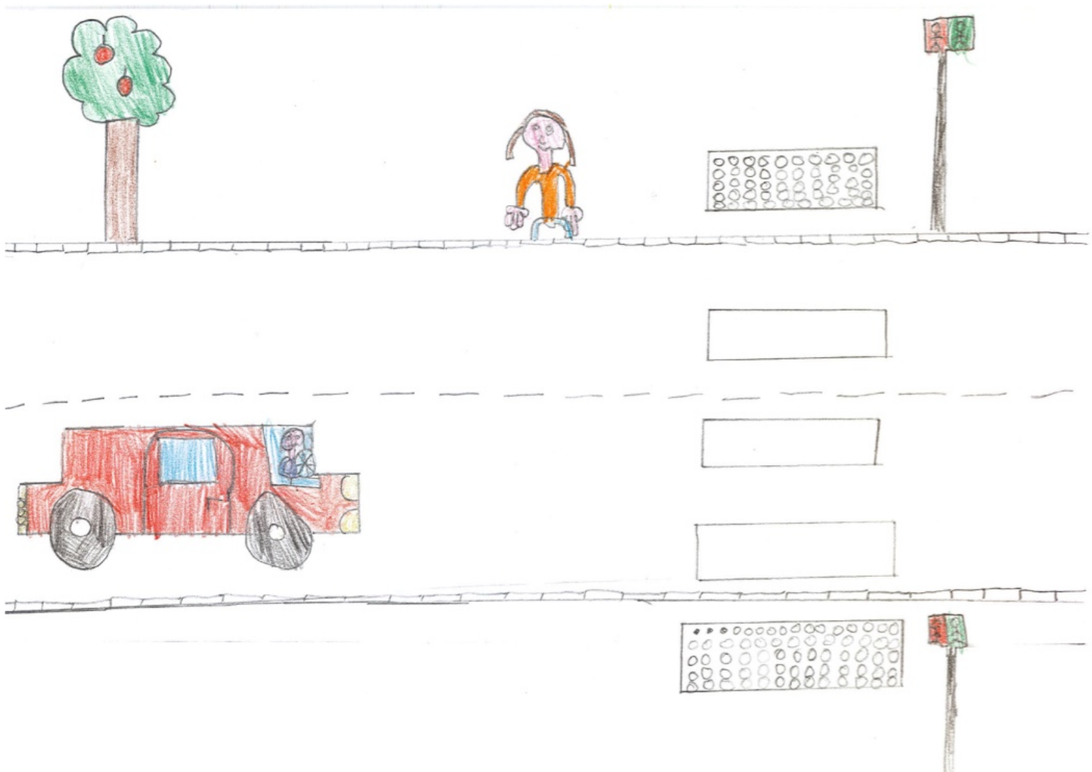

Figure 3. A first example of a drawing performed by one of our participant

Figure 4. A second example of a drawing performed by one of our participant

often include more characters than vehicles.

In the four traffic lanes identified in the drawings produced (pavement for pedestrians, bus/tram lane, cycle track and car lane), the 'car' lane is the most represented (from 27.59% to 65% of the drawings), followed by pavements (from 20.69% to 56.58%) and finally bus/tram lanes, which are the least represented (10.34% to 25%). It should be noted that cycle lanes are very rarely represented in the drawings (from 5.26% to 10%), whereas they are very present in the urban space that is so familiar to the participants in our study. Here again, the drawings differ greatly according to the schools in which the children attend: the number of traffic lanes represented increases for children attending schools located in moderate and high risk areas. In other words, even if this is only a statistically insignificant trend, the drawings produced by children attending schools in high-risk accident areas are becoming more complex and show multiple, multimodal roads (i.e., the presence of a bus/tram lane, a car lane and a cycle path on the same drawing).

Because road signs are such an integral part of our urban landscapes, and form the basis for learning the Highway Code and many of the prevention/awareness programs run in schools, it's only logical that children should frequently refer to road signs in their drawings. The main sign represented is the pedestrian crossing (up to 85 of the drawings include one). The pedestrian crossing therefore appears to be a central element, closely linked to the task of crossing the carriageway, which is of paramount importance to pedestrians. It should be noted that a large number of drawings are "collections" of signs in the sense that the traffic light (79.3%), pedestrian light (68.97%) and stop sign (65.52%) are all present. As with the road category, there is little signage for traffic lanes (bus, car, cyclist). On the other hand, there is no difference between the drawings produced by the children depending on the area in which they attend school, as far as these signs are concerned.

The category of vehicles is central to the study of representations of pedestrians, since they represent the main real danger to pedestrians. Although several types of vehicle were drawn by the children, the car was by far the most represented (from 45% to 65.79%). Buses and/or public transport are represented in more than a third of the drawings, a fact that is all the more interesting if we compare it with the low representation of bus lanes and associated signage. Generally speaking, the urban landscape in the drawings shows little variety of vehicles other than cars. Here again, there is no difference between the drawings produced by the children according to the area in which they attend school with regard to this signage.

E. Discussion

In this second study, we looked at the link between real (i.e., objectively established) accident risk and the representation of the urban environment in a population of child pedestrians aged 7 to 8, using drawings. Analysis of the 125 drawings collected yielded a number of interesting results.

The egocentric perspective is the perspective overwhelmingly present in the drawings produced by the children. This result is consistent with the Piagetian approach to the development of intelligence, according to which children aged 7-8 (i.e., the period between the pre-operational stage and the concrete operations stage) understand the world from their own point of view. The drawings produced generally concern a specific road scene, namely crossing the carriageway. This is objectively the most dangerous activity and the one that children are most made aware of from an early age. From the point of view of the development of spatial representations, these evolve gradually, from a collection of elements present in the physical environment to the linking together of these elements [47], finally leading to a general and coherent spatial representation.

The children's drawings are more elaborate and richer (in terms of the number of elements represented) as the real accident risk in their environment increases. Not only does the number of elements in the drawings increase quantitatively, but these elements are more closely linked to each other, to the point where they form a real scene. The representation becomes more precise and the distinction between traffic lanes is more frequently observed in the drawings produced by children attending schools located in high-risk accident areas. The only exception is the signage, which is richer and more frequent in the drawings produced by children attending schools in low accident risk areas. We can assume that this latter representation corresponds to a representation of road safety rules (institutional knowledge).

In other words, the actual level of exposure to the risk of collision with motorised vehicles has an impact on children's mental representations in the sense that mental representations appear to be denser and richer in the most exposed children. Their representation then becomes a global and unified whole, which is reminiscent of the second stage of Endsley's model [48] According to Endsley, the first stage in risk perception is the perception of the constituent elements of the environment, giving rise to drawings that are juxtapositions of elements present in the environment, with no real link (i.e., a "collection of elements" such as a car, signs, a pedestrian crossing). The whole thing is not staged but simply presented on paper. However, "scene" type representations, the frequency of which increases with the real accident risk, go beyond this level to present the links between elements (e.g., a car is represented on a lane intersected by a pedestrian crossing, people waiting at the side of the road).

The participants in the second study were asked to draw a picture of the things to look out for when moving around the city. The majority of the drawings included people other than the author her/himself, usually peers, instructors or onlookers. It is interesting to note that the drawings include as many cars as characters, despite the fact that the risks of collisions are objectively associated with motorised vehicles. Analysis of the drawings also shows that other people (especially adults) are an important source of information when travelling in an urban environment. This importance of others when travelling in physical environments has already been noted by several authors: the behaviour of others informs us in which direction to focus our attention [49] and enables us to anticipate certain behaviours of other pedestrians or drivers with whom the child shares the space [50]. In other words, as Granie points out [51][52][53], social norms condition us to share urban space by teaching us to interact with other users of this common space.

The development of risk representations should therefore be seen in the context of person-environment interaction: children are actors in their environment, acting on it just as the environment acts on them [54]. As [4] said, child pedestrian injury prevention can be characterized as a spectrum from active programs, designed to educate or train individuals to change their behavior, to passive interventions that increase the safety of products or environments in a manner that impacts all users. These "passive" interventions tend to be more costly and difficult to implement but are also more likely to result in real and sustained reductions in injury incidence.

Our results are in line with those which tend to show that it is not so much biological gender that determines risk perception as other factors such as the type of parental supervision according to gender or adherence to the gender stereotype [50].

While our study of mental representations (in this case, by means of drawings) has made it possible to identify certain relevant elements, it does not provide any information about the children's actual behaviour. So, as a way forward, we are already planning to study the link between the mental representations of child pedestrians and their actual behaviour when travelling in urban environments. Indeed, the link between 'perceived risk' and 'actual travel behaviour' is not all that logical: for example, a recent study [55] tends to show that, although a potential danger in their physical environment is correctly perceived and identified by young children (aged 7-8), they may adopt 'endangerment' behaviour (i.e., some children knowingly go into areas they perceive as dangerous). A combination of behavioural data and more subjective data is therefore desirable.

From a methodological point of view, although several data collection techniques can be used to investigate the mental representations of pedestrians (e.g., verbalizations concomitant with the activity of moving, verbalizations based on observation of static scenes), our study confirms that the use of drawing appears to be particularly suitable for questioning young people: it falls within their field of motor skills and particularly stimulates their interest. What's more, it's a technique that allows us to go beyond the limits of language, and is inevitably better suited to conveying a largely visual experience.

Finally, the results issued from our qualitative research highlights the interaction between children and their physical environment. The representations of subjects evolving in an environment richer in stimuli appear to be richer, denser and more interrelated. The elements represented are more numerous and more varied and, more importantly, the links between them are more frequent and better structured. Memory knowledge has a much more complex level of structuring, and this representation is more representative of individual experience than institutional knowledge. In Endsley's model [48], this type of representation constitutes the intermediate stage of situational awareness in dynamic environments. In memory, this representation forms the basis of the judgments and predictions that enable the decision-making process. This is why the approach based on risk representation is inseparable from the study of pedestrian behaviour. Finally, the parental challenge is paradoxical: where is the happy medium between guaranteeing the child's well-being and developing autonomy?

IV. General discussion

From a theoretical point of view, our results obtained in our two studies show how the pedestrian's skills would be dependent on the development of at least two simultaneous capabilities: visual exploration strategy and cognitive processing abilities. First, the visual sampling strategies tend to be systematic in younger, not focusing on specific areas or strategic areas and, with age, the visual exploration strategy is specified and is interested in the peripheral areas of the visual field [33][45]. This development led to a more accurate and relevant information extraction from visual environment in urban areas [27][28][29]. Second, cognitive development allows greater information processing capacity [17][18][19], thus taking a more rapid and effective decision. From a theoretical point of view the use of poor visual strategy combined with a cognitive inability to process so many information that explains more time decision-making among young pedestrians in a dense traffic environment.

Several methodological limits prevent us to generalize the results obtained. First, the two experiments were conducted inside the school, which resulted in to cause a feeling of observation. The pupils often sought to provide "the good answer" whereas we are interested in their own answer. If the experiment were led in the school, it was a question above all of preserving a medium familiar and reassuring for the pupils. Second, stimuli used in our experiment were only visual and the information in peripheral vision necessarily decreased by the size of the screen. But, for ethical and technical reasons, it was not possible to carry out the experiment in real outdoor environment. Third, stimuli used in our first experiment were static (i.e., pictures): So, in our actual new studies, dynamic stimuli (i.e., videos) will be used to introduce dynamic factors, such as motion of vehicles and motion of other pedestrians in the scene. Moreover, even if visual information are crucial, we will add sounds in the experimental material to place participants in a more naturalistic setting. Our two studies tend to demonstrate on the one hand, that the development of pedestrian skills is essentially based on visual exploration of surrounding environment and on the other hand, these skills increase with the development of more general cognitive abilities, these two skills being crucial in the mental representation of children about hazards in their physical environments.

Nowadays, various techniques can be used to teach these skills, including classroom curricula, video or web-based instruction, real life practice with adult supervision and instruc-

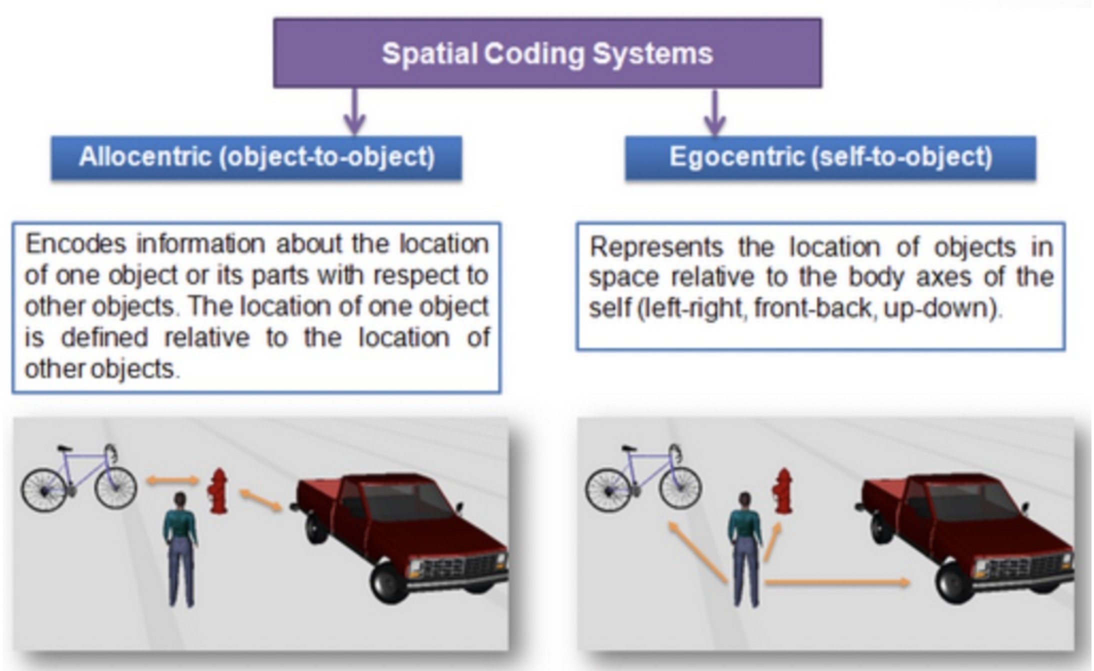

Figure 5. Allocentric vs. Egocentric Spatial Processing according to [45]

tion, and internet or smartphone-based virtual reality (VR) training [8][56][57][58].

V. Conclusion and Future Works

By using an experimental approach and eye-tracking techniques, our first study aimed to investigate the impact of one individual factor (Age) and one environmental factor (Traffic density) on three behavioural indicators related to competencies of very young pedestrians (aged 3-10 years): (i) the decision (i.e., "to cross" versus "not to cross the street"), (ii) the time spent in milliseconds to make this decision and (iii) the visual exploration of urban scenes displayed on pictures. This study is the first one to our knowledge which investigates visual exploration of urban scenes for very young children (under 4 years old). Using eye-tracking technique is interesting for several reasons. Visual exploration is a irrepressible behavior. Specifically, for young children with limited language capacity, the use of eye-tracking allows comparison with older children and adults. As we reported previously, to our knowledge, no study has looked at the visual exploration of such young pedestrians (under 4 years). Young audiences are more difficult to approach ethically. Younger cannot be put in a situation in real conditions, accompanied due to their motor skills development.

Our second study, based on drawings performed by young children, provided important findings about what is crucial for these young pedestrian in their physical environment. In other words, the first study offered quantitative and objective data while the second one offered qualitative and subjective data.

Although changes in policy, planning, and the built environment can have an important potential to improve young pedestrian safety, many of the most commonly promoted strategies to address pedestrian risk focus on individual-level interventions to improve the skills or behavior of child pedestrians, their adult caregivers, or the drivers with whom they interact. Crossing the street is a complex task that requires the ability to identify a safe place to cross, recognize the relative speed of a moving car, judge the distance of the automobile, and quickly make a decision about whether it is safe to enter the roadway. So, all individuals must learn how to be a pedestrian. Rather than thinking of pedestrian safety as a body of knowledge to absorb, it is most useful to characterize it as a series of cognitive, perceptual, and motor skills that must be mastered to navigate the road traffic environment.

Acknowledgment

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