Journal of Safety Research 88 (2024) 1–7

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Children's risk assessment in street crossing using virtual reality

Ole Johan Sando *, Rasmus Kleppe, Ellen Beate Hansen Sandseter

Queen Maud University College, Trondheim, Norway

ARTICLE INFO

Keywords:
Street crossing
Children
Virtual reality
Risk assessment
Safety

ABSTRACT

Introduction: Crossing streets represents a risky task for children where they have to assess both the probability and harm severity of being hit by a vehicle. To cross streets safely, children must perceive and interpret the traffic environment and scale their movements to the flow of traffic. Their ability to gather information about the surrounding environment through visual search strategies is essential in this process. This study aimed to explore children's street crossing behaviors and to identify successful risk-assessment strategies. *Method:* Virtual reality (VR) with built-in eye tracking was used for this investigation; 55 children between 7 and 10 years old completed six street crossing tasks with varying complexity and difficulty. *Results:* Varying competencies in street crossing were demonstrated among the children. Those who crossed safely looked to the left and right more often to check for traffic and spent more time assessing the traffic environment by following oncoming vehicles with their gaze before crossing than those who crossed dangerously. No apparent differences between children who crossed safely and those who crossed dangerously were found while crossing. *Conclusions:* The findings suggest that dangerous street crossings were, on different levels, related to assessment time before crossing, visual search strategies during assessment time, and the tasks harm severity and probability risk. *Practical Applications:* Future research could suggestively include indicators such as assessment time and visual search strategies, and tasks could discern harm severity and probability risk. These indicators might also be considered for training programs aiming to enhance children's pedestrian safety.

1. Introduction

Accidents related to transportation are the leading cause of injuries in Norway and globally, and motorized vehicles are involved in many of these (Nesje et al., 2019). Although the majority of severe injuries occur when children are passengers in cars, street crossings also cause serious injuries and death for children. Crossing a street represents a complex task that challenges children's perceptual and cognitive skills, as well as their motor abilities and decision-making. Human decision-making in such a changing environment can be linked to situational awareness, which is suggested to be gained through the perception of elements in the current situation, comprehension of their integrated meaning, and the projection of future status (Endsley, 1995). Successfully identifying traffic that might be dangerous and incorporating information about different factors and directions of traffic into a holistic perception of the situation and future events are essential to crossing streets safely (Meir et al., 2013). In line with this, children's visual search skills (Barton & Morrongiello, 2011; Whitebread & Neilson, 2000) and their ability to resist interfering of irrelevant stimuli (Tabibi & Pfeffer, 2003) are significant factors affecting their street crossing behaviors. Moreover, taken together, processing and interpreting the flow of traffic is one of the most-pronounced deficits in young children's street crossing abilities (Bart et al., 2008).

Virtual reality (VR) allows for controlled pedestrian settings where the user interacts with a realistic virtual world without being at risk (Meir et al., 2013; Schwebel et al., 2008). Several previous studies have examined street crossing behavior using VR (Sonja & Klaus, 2020). Among studies with children as subjects, Morrongiello et al. (2020) found that boys choose smaller gaps between vehicles to cross streets, initiate crossing sooner, perform more evasive actions, and look at traffic more while crossing. In addition, boys were hit more often and experienced more close calls than girls did (Morrongiello et al., 2020). However, Wang et al. (2020) did not find sex to play a significant role. Rather, their results showed that individual differences in children influenced their crossing behaviors, and children lower in sensation-seeking missed more opportunities to cross and crossed the road less efficiently. In another study, younger children were more inclined to cross the street and cross at a higher speed than older children,

* Corresponding author at: Department of Physical Education, Queen Maud University College, Thrond Nergaards veg 7, N-7044 Trondheim, Norway.
E-mail address: ojs@dmmh.no (O.J. Sando).

https://doi.org/10.1016/j.jsr.2023.10.002
Received 28 October 2022; Received in revised form 8 June 2023; Accepted 16 October 2023
Available online 3 November 2023
0022-4375/

suggesting that they are less aware of potential hazards when crossing (Meir et al., 2013). Furthermore, traffic characteristics such as density and speed were found to influence children's crossing behaviors, and children relied more on distance information than on the speed at which vehicles were traveling (Morrongiello et al., 2015; Wang et al., 2020). Children's response times were similar for one- and two-directional traffic in a study by Meir et al. (2013).

To choose a safe gap between traffic in which to cross safely, children have to scale their movements to vehicles coming from different directions (Morrongiello et al., 2015). A key element in street crossing is to precisely synchronize and adjust one's movement to a gap in traffic, an ability that is found to develop during childhood (O'Neal et al., 2018). Research indicates that when children make the initial crossing decision, it is based solely on visual information (Morrongiello et al., 2021). Characteristics of children's search strategies in VR have highlighted that they monitor traffic more closely while crossing when vehicles are closer to the child and the risk of being hit is greater (Morrongiello et al., 2015). Compared to adults, children direct more of their visual attention to the center of the visual scene rather than to the far left and right (Tapiro et al., 2018). Moreover, they often fail to check traffic while they are in the process of crossing a street, thus risking being in the path of an oncoming vehicle without knowing it (Morrongiello et al., 2015). Using eye-tracking data, Tapiro et al. (2020) demonstrated that children were less capable of focusing on relevant factors for crossing safely when the environment was more visually loaded, possibly causing them to miss critical information. Schwebel et al. (2014) found children's attention to traffic to be inconsistent in a randomized controlled trial on teaching children safe street crossing, indicating that children aged 7 and 8 are sufficiently attentive to traffic and that it is the cognitive aspects of crossing behavior that may be trained to improve safety in their street crossings. The combined knowledge about how children use their gaze in virtual reality to assess and manage risks is limited and represents a gap in the literature.

This study uses VR and eye tracking to develop knowledge about children's risk assessment in street crossings. An additional aim of the study is to identify preliminary indicators for successful strategies. We explore the following research question: What indicators of children's behavior predict successful risk-assessment strategies in street crossings?

2. Materials and methods

This study is conducted to the project ViRMa. ViRMa is funded by the research council of Norway (grant 324155) and continues from 2021 through 2024. The data in this study were collected in the spring of 2022 and are part of the study's pilot. The Norwegian Social Science Data Service approved the study.

2.1. Participants

The participants were recruited from a primary school in a rural area in Mid-Norway. The school was located a 30-minute drive outside a large Norwegian city. All children in the second (born in 2014), third (2013) and fourth (2012) grades at the selected school were invited to participate. Among the 76 children in these three grades, we received written and informed consent to participate from the guardians of 64 children. Two of these children did not want to participate and thus were not included in the sample. The original sample, therefore, comprised 62 children, 27 girls and 35 boys. Of these, 13 attended second grade, 26 third grade, and 23 fourth grade. Among the 62 children who started the VR simulation, two failed to complete the test, a second-grader and a third-grader; one felt sick, and the other thought the tasks were too complicated. After removing invalid VR tasks due to intentional or technical errors, 55 children (31 boys and 24 girls) were included in the further analysis. Their average age was 8.9 years (SD = 0.8), ranging from 7.2 to 10.1 years old.

2.2. Virtual environment

Two urban traffic environments were developed by the VR company Nordic Neurotech. The urban traffic environments were based on a generic urban expression so that children from both rural and urban places would accept the environment as typical. During testing, none of the participants indicated otherwise. In both environments, children were given three different tasks with varying risks (i.e. harm severity and probability of being hit; Atkinson, 1957; Young et al., 1992). Since the speed of all vehicles was set at 5 m per second, the tasks' probability risk was adjusted through traffic density and by including traffic from one direction or two directions. We aimed to gradually increase the probability risk of the tasks by increasing the amount and direction of traffic in the tasks. In three tasks (bike road 1, 2 and traffic 1), one lane has traffic from one direction. In traffic 2 there are two lines of traffic from one direction, while bike road 3 and traffic 3 were the most complex (thereby increasing probability risk) with two lanes of traffic from both directions. The traffic speed was kept the same for all tasks to study the effect of varying traffic complexity rather than the impact of different traffic speeds.

Traffic density decreases over time in all tasks (spawn frequency), affording children increasing possibilities to cross as the task progresses. Harm severity risk levels were adjusted by either bicycles (lower harm severity) or cars (higher harm severity). The first environment represented a bikes-only road including buildings, trees and grass surfaces (Fig. 1, left side). In the first task, bikes came from the left with a starting spawn frequency of 5 s (25 m) between each cycle, with a maximum spawn frequency of 12 s (60 m). The spawn frequency decreased gradually over the first 60 s (decrease time) of this task. In the second task, bikes came from the right, whereas bikes came from both directions in the third task. The second environment replicates a busy urban street with buildings, sidewalks, and parked cars (Fig. 1, right side). The first task included only cars from one direction; in the second task, both cars and bikes approached from one direction; and in the third task, bikes and cars came from both directions. The spawn frequencies and times from minimum to maximum spawn frequency in each task are presented in Table 1.

2.3. Procedure

We used the HTC VIVE Pro Eye VR headset to run the VR simulation with Tobii Pro integrated eye tracking. An area of 7 × 6 m was set up and calibrated. Four SteamVR 2.0 Base Stations were used, one in each corner. The child wore five Vive Trackers (v3) to identify the position of their hands, feet, and waist. The data collection was conducted during school hours, and the participating children were taken out of class individually to perform the VR tasks. After familiarizing the child with the equipment and safety routines, the eye-tracking calibration procedure in VIVE was performed. Next, a warm-up session was conducted to enable children to become accustomed to the VR environment and to walking around with the equipment. The warm-up took place in a park-like setting. The child could see his or her hands and feet in the simulation, and the VIVE trackers enabling this were calibrated during the warm-up. A researcher followed the child constantly and held the headset wire to ensure the child's safety (Fig. 2).

When the child felt ready to start the test, usually after 3–5 min, the HTC VIVE surround-sound headset was put on, and further instructions about the tasks were automatically given to the child from the software. These pre-recorded audios ensured that all children received the exact same instructions. The child was not informed about the gradual decrease in traffic density. Bike road 1 was completed when the child reached the red-outlined rectangle (see Fig. 1) on the opposite side of the road. After finishing the task, the child turned around and seamlessly entered the next bike road task. When the last bike road task was completed, the child entered an empty holodeck to be repositioned correctly before the traffic tasks. When she or he had entered the correct

Fig. 1. Screenshots of the virtual bike-road environment (Bike road 3) and the virtual traffic environment (Traffic 3).

Table 1
Task descriptions.

Task	Directions	Illustration	Min spawn	Max spawn	Decrease time
Bike road 1	Left		5 s/25 m	12 s/60 m	60 s
Bike road 2	Right		2 s/10 m	10 s/50 m	60 s
Bike road 3	Both		4 s/20 m	15 s/75 m	80 s
Traffic 1	Right		4 s/20 m	12 s/60 m	60 s
Traffic 2	Left		4 s/20 m	13 s/65 m	60 s
Traffic 3	Both		3 s/15 m	12 s/60 m	60 s

Fig. 2. The experimental scene and equipment.

position, the child was automatically taken to the first traffic task. Transitions between the traffic tasks worked seamlessly, as they had for the bike road tasks. If children were 'hit,' they were taken to the holodeck before being given a second trial to complete the task. In order to have the same number of tasks for each child, only the first trial for each task was included in the analysis. To account for potential carryover effects, we deliberately decided to maintain a fixed order of tasks instead of randomizing them. This approach facilitated equitable comparisons of children's performance within each task. Additionally, the fixed order allowed children to gradually acclimate to the tasks, starting with easier ones and progressing to more challenging ones. Consequently, we anticipated a reduced likelihood of children opting out of the test.

2.4. Analysis

Two researchers, independent of each other, replayed all tasks manually to identify technical errors or intentional failures, and these were removed from the sample. The data from the VR simulation were stored in .txt and processed in MATLAB (R2021b) to generate measures on street crossing for each child. Excel exports from MATLAB were imported to STATA (MP 17) to conduct descriptive statistics, multilevel logistic regression and independent t-tests. Given the hierarchical structure of the data, with several observations of each child and the dichotomous outcome variable, mixed-effects logistic regression (StataCorp, 2013) was used to investigate the associations between dangerous crossings and age, sex, assessment time, time used to cross the street, and maximum speed while crossing. Intraclass-correlation analysis was used to explore the variance located at the child level.

Additionally, a gaze analysis of selected cases based on their measured crossing behavior was conducted to explore successful and unsuccessful street crossing strategies. This analysis was conducted by replaying the VR simulations in Observer XT 14 behavior coding, analysis, and management software for observational data (Zimmerman et al., 2009). The child's eye orientation was illustrated in the replay by a blue line (see Fig. 3), and one researcher coded the child's use of his or her gaze by replaying the simulation at one-fifth of the original speed. Data from Observer XT were exported to Excel and imported to STATA (MP17) for statistical analysis.

2.5. Measures

The data from the VR simulation were recorded in 90 Hz. From these data, the following measures were obtained using MATLAB:

1. Hits (count) – the child was hit by a vehicle;
2. Near hits (count) – the child was closer than 4 m to the front of a vehicle (0.8 s from being hit);
3. Dangerous crossings (count) – the child was hit or nearly hit;
4. Assessment time (seconds) – time elapsed from the opening of the task to the child starting to cross;
5. Crossing time (seconds) – time used to cross the street for children who were not hit; and
6. Maximum speed (meters per second) – the child's maximum speed obtained in the task when crossing.

The following measures were obtained from the gaze analysis in Observer XT:

1. Left/Right before crossing (count) – gaze more than 30 degrees off-center to the left/right of the child while assessing;
2. Left/Right crossing (count) – gaze more than 30 degrees off-center to the left/right of the child while crossing;
3. Oncoming cars/bikes assessing (seconds) – gaze fixated on an oncoming car or bike while assessing;
4. Oncoming cars/bikes crossing (seconds) – gaze fixated on an oncoming car or bike while crossing;
5. Leaving cars/bikes assessing (seconds) – gaze fixated on a leaving car or bike while assessing; and
6. Leaving cars/bikes crossing (seconds) – gaze fixated on a leaving car or bike while crossing.

3. Results

Descriptive statistics for the six tasks are presented in Table 2. No children were hit in the first two bike road tasks, and the most hits occurred in the two tasks with traffic traveling from both directions, bike road 3 and traffic 3. Near hits occurred frequently on bike road 3, traffic 2 and traffic 3. The tasks with the highest numbers of dangerous crossings were bike road 3, traffic 2, and traffic 3. Average assessment

Table 2
Descriptive statistics for hits, near hits, dangerous crossings, assessment time (mean, SD), crossing time for those who were not hit (mean, SD) and maximum speed (mean, SD) for the six VR tasks (N = 55 children).

Task	Hits	Near Hits	Dang. crossing	Asst. times	Cross. times	Max speed
Bike road 1	0	6	6	16 (8)	2.9 (1.3)	1.6 (0.6)
Bike road 2	0	8	8	21 (7)	3.7 (1.1)	1.9 (0.8)
Bike road 3	9	12	21	21 (8)	2.2 (1.0)	2.0 (0.8)
Traffic 1	1	7	8	15 (9)	3.2 (1.3)	2.2 (1.2)
Traffic 2	5	16	21	21 (12)	3.5 (1.1)	2.2 (1.3)
Traffic 3	10	10	20	23 (15)	3.1 (1.2)	2.1 (0.7)

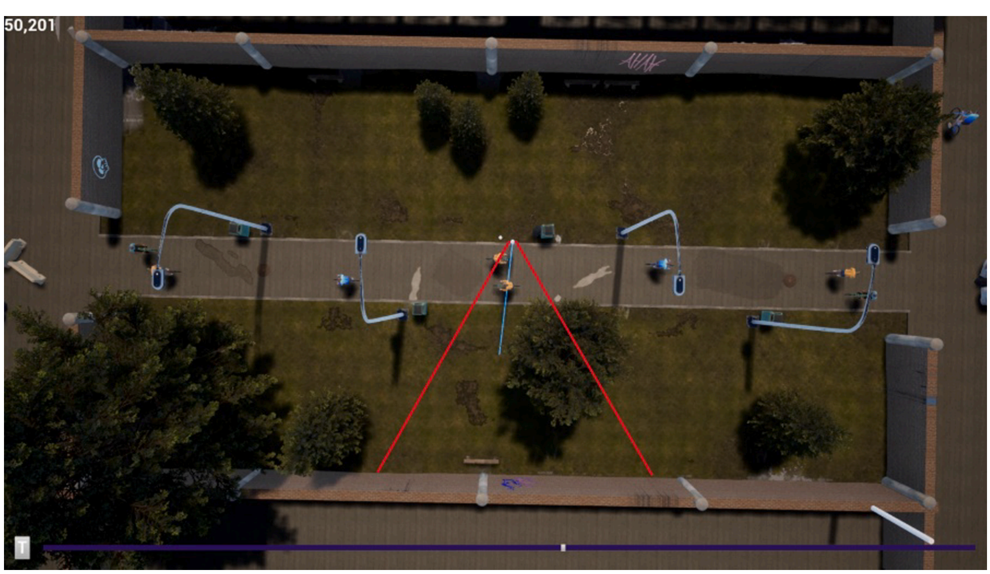

Fig. 3. Illustrates the perspective used in the in-depth analysis of children's eye orientation (blue line) and the definition of looking left or right (red lines).

time was lowest in the two tasks with the lowest risk, bike road 1 and traffic 1, and similar in the other tasks. Time used to cross the street (for those not hit) was relatively stable at about 3 s across the six tasks. Maximum speed while the child was crossing was lower in the first bike road task and relatively stable at about 2 m per second in the other tasks.

The results from the mixed effects logistic regression (N = 330 observations) indicate that 18% of the variance in dangerous crossing was located at the child level, suggesting substantial differences between children in how safely they crossed in the six tasks. No significant relationship was established between crossing dangerously and the child's age (ß=-0.12, p =.506) or being a boy (ß=0.40, p =.312). Controlling for the child's age and sex, the time used to cross the street (ß=0.08, p =.267) and maximum speed while crossing (ß=0.05, p =.745) were also unrelated to dangerous crossing. However, using multilevel logistic regression analysis controlling for age and sex, assessment time (ß=-0.04, p =.022) was significantly negatively related to dangerous crossings.

In all, 14 children crossed safely in all tasks, whereas 14 children crossed dangerously in more than three of the tasks (M = 3.4 dangerous crossings, SD = 0.6). Nine girls and five boys, with an average age of 9.1 years (SD = 0.7), crossed safely in all the tasks. Four girls and 10 boys, with an average age of 9.1 years (SD = 0.9), crossed dangerously in more than half the tasks.

The total assessment time before crossing was significantly higher in the safe group in all tasks using an independent *t*-test (p = 0.001). However, the average crossing time and maximum speed while crossing were not significantly different between the two groups for any of the six tasks. Descriptive statistics for these outcomes for the two groups are presented in Table 3.

A gaze analysis of the crossing behavior of the two groups was conducted for the tasks bike road 3, traffic 2, and traffic 3. These tasks were selected because they were shown to be the most risky based on the number of dangerous crossings (Table 2). Before crossing the street, children in the safe group checked by looking to their right and to their left significantly (p = 0.001) more often than the dangerous crossing group did. Both groups looked left and right before crossing more often in the tasks with traffic coming from both sides (bike road 3 and traffic 3) compared to traffic from one direction (traffic 2). There were no significant differences between the safe group and the dangerous group in how often they checked to the left or right while crossing the street (see Table 4).

The eye-tracking data revealed that many children monitored the traffic by following oncoming vehicles (cars or bikes) with their gaze before they searched for the next oncoming vehicle (see Table 5). On average, for the three tasks, children in the safe group spent 15 s (SD = 8.6) watching oncoming vehicles before crossing, while the dangerous group spent 4 s watching (SD = 3.6), and this difference was significant (p = 0.001). Children in both groups spent much less time watching vehicles that had passed them and were moving away from them. Children in the safe group watched these vehicles for 1.8 s (SD = 1.7), which is significantly (p = 0.01) more than the dangerous group with an average of 0.8 s (SD = 1.1). There were no significant differences in the amount of time spent watching oncoming or leaving vehicles while crossing between the safe group (oncoming M = 0.4, SD = 0.6; leaving M = 0.1 SD = 0.3) and dangerous group (oncoming M = 0.8, SD = 1.3; leaving M = 0.1, SD = 0.4).

When assessment time was controlled for, there were no significant differences between the safe and dangerous groups in regards to how much of the assessment time they spent watching vehicles. The dangerous group spent 56% (SD = 24) of the assessment time watching oncoming vehicles and 9% (SD = 11) of the time watching leaving vehicles. Similarly, the safe group watched oncoming vehicles 61% (SD = 22) of the assessment time and leaving vehicles 8% (SD = 7) of the assessment time. In tasks with cars and bikes (traffic 2 and traffic 3), both groups of children paid more attention to cars than to bikes. In these two tasks, the 28 children spent 53% (SD = 18) of the assessment time watching cars, and 20% (SD = 13) of the time was spent watching bikes.

Table 3
Descriptive statistics for assessment time (mean, SD), crossing time for those who were not hit (mean, SD) and maximum speed (mean, SD) for the six VR tasks divided by groups' safe crossings (N = 28 children).

Task	Safe group (N = 14)			Dangerous group (N = 14)		
	Asst. Time	Cross. time	Max speed	Asst. time	Cross. time	Max speed
Bike road 1	22 (11)	3.2 (1.4)	1.3 (0.2)	11 (3)	3.1 (1.9)	1.6 (0.5)
Bike road 2	28 (8)	3.6 (1.9)	1.6 (0.4)	14 (4)	3.6 (1.5)	1.8 (0.6)
Bike road 3	28 (10)	2.4 (1.0)	1.8 (0.4)	15 (4)	2.5 (1.0)	1.8 (0.6)
Traffic 1	23 (8)	3.4 (0.8)	2.4 (2.0)	8 (3)	3.7 (2.1)	2.1 (0.5)
Traffic 2	30 (14)	3.8 (0.9)	2.3 (2.1)	13 (6)	3.2 (0.9)	2.0 (0.4)
Traffic 3	36 (16)	3.2 (0.9)	1.9 (0.7)	10 (7)	3.2 (1.8)	1.9 (0.7)
Average	20 (10)	3.5 (1.4)	1.9 (0.8)	12 (3)	3.4 (1.3)	1.9 (0.4)

4. Discussion

The findings of this study indicate that children between 7 and 10 years of age have varying skills for assessing and managing risk in crossing streets. Among the 330 completed tasks in this study, children were hit in 6% of the tasks and nearly hit in 18% of the tasks. Children were hit mainly in tasks with higher traffic density and traffic coming from two directions (i.e., tasks with a higher probability risk). A quarter of the children crossed safely in all six tasks, whereas a quarter crossed dangerously in three or more tasks. In addition, children spent more time assessing traffic before crossing and reached a higher maximum speed in tasks with higher traffic density. These findings support previous research suggesting that characteristics of the traffic environment influence children's crossing behaviors and how safely they cross (Morrongiello et al., 2015; Wang et al., 2020). While children looked to the left and right to check for traffic more frequently in tasks with traffic coming from two directions, their assessment time was similar to that of other tasks with similar traffic density from one direction, a finding that aligns with a previous study (Meir et al., 2013). The high variation among children in how safely they cross a street provides possibilities for understanding what may characterize successful risk-assessment strategies in street crossing.

Building on the work of Endsley (1995), children who crossed dangerously may have failed to perceive the relevant elements in the environment, to combine their integrated meaning successfully, or to project the future status correctly. Assessment time indicates how much time children spent attempting to perceive relevant elements in the environment before deciding to cross. Higher assessment times were positively related to safe crossings, and children who crossed safely in all tasks spent significantly more time assessing than the quartile that crossed dangerously. This increased assessment time enabled these children to check to their left and to their right more often and to spend more time following oncoming vehicles with their gaze. Some children who were hit did not check in both directions before crossing and, thus, were unaware of the oncoming vehicle that hit them, as previous studies found (Morrongiello et al., 2015). The results of the present study suggest that taking sufficient time to assess and perceive the traffic environment by following oncoming vehicles and checking in both directions is a successful risk-assessment strategy.

While children who crossed safely spent more time watching vehicles before crossing, the percentage of the assessment time used to monitor oncoming vehicles is about 60% for both the safe and dangerous groups.

Table 4
Descriptive statistics for the number of times children checked to the left and right before crossing (B) and while crossing (C) (mean, SD) for bike road 3, traffic 2 and traffic 3, divided by groups of children (N = 28 children).

	Safe group (N = 14)				Dangerous group (N = 14)			
Task	Left B	Right B	Left C	Right C	Left B	Right B	Left C	Right C
Bike road 3	3.8 (1.7)	4.0 (2.5)	0.3 (0.6)	0.3 (0.5)	2.0 (1.2)	1.8 (1.6)	0.6 (0.6)	0.4 (0.5)
Traffic 2	1.9 (1.1)	0.9 (1.0)	0.9 (0.5)	0.1 (0.3)	1.5 (0.9)	0.7 (1.1)	0.9 (0.3)	0.1 (0.4)
Traffic 3	5.3 (2.8)	5.7 (2.8)	0.1 (0.4)	0.5 (0.7)	1.9 (1.9)	2.3 (1.9)	0.2 (0.4)	0.8 (0.4)
Average	3.7 (2.4)	3.5 (3.0)	0.5 (0.6)	0.3 (0.5)	1.8 (1.4)	1.6 (1.6)	0.6 (0.5)	0.4 (0.5)

Table 5
Descriptive statistics for the number of seconds children spent watching oncoming (O) and leaving (L) cars and bikes before crossing (mean, SD) for bike road 3, traffic 2 and traffic 3, divided by groups of children (N = 28 children).

	Safe group (N = 14)				Dangerous group (N = 14)			
Task	O. Cars	O. Bikes	L. Cars	L. Bikes	O. Cars	O. Bikes	L. Cars	L. Bikes
Bike road 3	–	8.6 (2.1)	–	1.9 (1.4)	–	3.1 (2.6)	–	1.0 (1.3)
Traffic 2	15 (6.8)	4.1 (3.0)	0.4 (0.6)	0.3 (0.6)	5.1 (3.8)	1.1 (0.8)	0.2 (0.4)	0.1 (0.4)
Traffic 3	10 (6.7)	5.7 (3.8)	1.8 (1.7)	0.9 (1.3)	2.3 (3.0)	1.1 (1.0)	0.8 (0.0)	0.4 (0.6)
Average	13 (7.1)	6.1 (3.5)	1.1 (1.5)	1.0 (1.3)	3.9 (3.6)	1.8 (1.9)	0.5 (0.7)	0.5 (0.9)

Both groups also spent much less time watching leaving vehicles than watching oncoming vehicles, suggesting that children directed their attention towards vehicles that represented a threat to them and influenced their possibility of crossing. Additionally, children were more attentive to cars than to bikes, which might be related to the increased injury severity of being hit by a car compared to a cyclist. These findings support the results of Schwebel et al. (2014) indicating that children in this age group are sufficiently attentive to traffic and aware of essential environmental elements, including discriminating between harm severity levels.

The measures obtained on children's behavior while crossing a street do not indicate any clear differences between children who cross safely and those who cross dangerously. The time used to cross the street, maximum speed while crossing, the number of times they look to the left and right, and their attention to oncoming and leaving vehicles while crossing were similar for the two groups in the present study. The results indicate that many children do not check to the left and to the right while crossing, a finding in accordance with Morrongiello et al. (2015). It must also be noted that children in the dangerous group direct a somewhat higher level of attention towards oncoming cars while crossing than the children in the safe group. Although this difference is not significant in the present sample, this increased attention to oncoming vehicles may be related to the more risky crossing behavior in the dangerous group since children have previously been found to be more attentive to cars when they are closer and the risk of being hit is higher (Morrongiello et al., 2015). Nevertheless, the results of this study suggest that the main difference between the children who cross safely and those who cross dangerously is related to their assessment before crossing and not to their behavior while crossing.

4.1. Limitations and future research directions

The results of this study build on a cross-sectional pilot study, which has limitations. The number of children who participated in this study is relatively low. Moreover, the sample is from one school in Norway with a homogenous population, and to what extent the subjects in this study represent a broader population is unknown. This calls for a cautious generalization of the findings and suggests that future studies with more participants are needed to confirm this study's findings. Although the present study has successfully used eye-tracking data to measure children's attention to traffic before and while crossing, the methods used to gather this information were time-consuming and relied on a researcher's interpretation of the data. This process could be automated with better data output and standardized algorithms for interpreting eye-tracking data.

Another limitation of this study is the fixed order of tasks, which may have introduced potential order effects or sequencing biases. By maintaining a predetermined order, we aimed to ensure fair comparisons of children's performance within each task and enable gradual task progression from easier to more challenging ones. However, this design choice may have influenced participant responses and performance due to carryover effects. A randomized task order could have provided valuable insights into the impact of task sequence on children's outcomes and allowed for better control of order effects. Given the limited sample size of children, analyzing and accounting for the multitude of possible task order combinations would have been challenging. Thus, the generalizability and internal validity of the study may be affected by the fixed task order.

Furthermore, tasks assigned in VR can never fully replicate the complexity and multiple factors involved in real-world street crossing. For instance, the traffic speed was constant for all tasks; no other pedestrians were present; and the child could not seek eye contact with the cyclists or motorists. Nevertheless, future studies could build on the findings of this study to develop rigorous indicators for successful risk-assessment strategies in street crossing and to develop accurate measures of children's attention to different objects in street crossing tasks using eye tracking in VR.

5. Conclusions

The findings of this study imply several preliminary indicators for studying 7- to 10-year-old children's street crossing strategies. To what degree children crossed dangerously (i.e., were hit or almost hit by a vehicle) was related to the time they used to assess the traffic environment before starting to cross. Additionally, in the assessment process, children who crossed safely used visual search strategies to direct their attention to oncoming traffic. This probably enabled them to perceive relevant environmental elements and to decide when it was safe to cross. The findings further indicate that children were aware of probability risk and harm severity and that those factors affected their assessments. Thus, the study's findings could be basis for further research on how children process and interpret visual information in street-crossing situations.

6. Practical applications

Future research investigating children's street crossing could suggestively include indicators such as children's assessment time before crossing, visual search strategies during assessment time, and tasks discerning harm severity and probability risk. These preliminary indicators might also be considered for training programs aiming to enhance children's pedestrian safety. Children aged 7 to 10 years could be taught the importance of spending at least 10 s observing oncoming traffic before crossing a street and looking left and right twice at a minimum to check for traffic. Children could also be taught that traffic coming from both sides makes crossing dangerous and that they need to pay extra attention in such situations.

Funding

The Norwegian Research Council supported this work (Project number: 324155). The funding sources had no involvement in any phase of the research project.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data used in this article are not openly available because the research data are confidential.

References

Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review, 64*(6p1), 359.

Bart, O., Katz, N., Weiss, P. L., & Josman, N. (2008). Street crossing by typically developed children in real and virtual environments. *OTJR: Occupation, Participation and Health, 28*(2), 89–96. https://doi.org/10.3928/15394492-20080301-01

Barton, B. K., & Morrongiello, B. A. (2011). Examining the impact of traffic environment and executive functioning on children's pedestrian behaviors. *Developmental Psychology, 47*(1), 182.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*(1), 32–64. https://doi.org/10.1518/001872095779049543

Meir, A., Parmet, Y., & Oron-Gilad, T. (2013). Towards understanding child-pedestrians' hazard perception abilities in a mixed reality dynamic environment. *Transportation Research Part F-Traffic Psychology and Behavior, 20*, 90–107. https://doi.org/10.1016/j.trf.2013.05.004

Morrongiello, B. A., Corbett, M., Milanovic, M., & Beer, J. (2015). Using a virtual environment to examine how children cross streets: Advancing our understanding of how injury risk arises. *Journal of Pediatric Psychology, 41*(2), 265–275. https://doi.org/10.1093/jpepsy/jsv078

Morrongiello, B. A., Corbett, M., & Stewart, J. (2020). Understanding sex differences in children's injury risk as pedestrians. *Journal of Pediatric Psychology, 45*(10), 1144–1152. https://doi.org/10.1093/jpepsy/jsaa072

Morrongiello, B. A., Corbett, M. R., & Vander Hoeven, E. (2021). Children's street crossing performance when auditory information about traffic is lacking. *Transportation Research Part F: Traffic Psychology and Behavior, 77*, 149–155.

Nesje, E., Valøy, N. N., Krüger, A. J., & Uleberg, O. (2019). Epidemiology of paediatric trauma in Norway: A single-trauma centre observational study. *International Journal of Emergency Medicine, 12*(1), 18. https://doi.org/10.1186/s12245-019-0236-9

O'Neal, E. E., Jiang, Y., Franzen, L. J., Rahimian, P., Yon, J. P., Kearney, J. K., & Plumert, J. M. (2018). Changes in perception–action tuning over long time scales: How children and adults perceive and act on dynamic affordances when crossing roads. *Journal of Experimental Psychology: Human Perception and Performance, 44*(1), 18.

Schwebel, D. C., Gaines, J., & Severson, J. (2008). Validation of virtual reality as a tool to understand and prevent child pedestrian injury. *Accident Analysis & Prevention, 40*(4), 1394–1400. https://doi.org/10.1016/j.aap.2008.03.005

Schwebel, D. C., McClure, L. A., & Severson, J. (2014). Teaching children to cross streets safely: A randomized, controlled trial. *Health Psychology, 33*(7), 628.

Sonja, S., & Klaus, B. (2020). Virtually the same? Analysing pedestrian behavior by means of virtual reality. *Transportation Research Part F: Traffic Psychology and Behavior, 68*, 231–256. https://doi.org/10.1016/j.trf.2019.11.005

StataCorp, L. (2013). Stata multilevel mixed-effects reference manual. *College Station, TX: StataCorp LP, 9*(10).

Tabibi, Z., & Pfeffer, K. (2003). Choosing a safe place to cross the road: The relationship between attention adn identification of safe and dangerous road-crossing sites. *Child: Care, Health and Development, 29*(4), 237–244. https://doi.org/10.1046/j.1365-2214.2003.00336.x

Tapiro, H., Oron-Gilad, T., & Parmet, Y. (2018). The effect of environmental distractions on child pedestrian's crossing behavior. *Safety Science, 106*, 219–229. https://doi.org/10.1016/j.ssci.2018.03.024

Tapiro, H., Oron-Gilad, T., & Parmet, Y. (2020). Pedestrian distraction: The effects of road environment complexity and age on pedestrian's visual attention and crossing behavior. *Journal of Safety Research, 72*, 101–109. https://doi.org/10.1016/j.jsr.2019.12.003

Wang, H., Gao, Z., Shen, T., Li, F., Xu, J., & Schwebel, D. C. (2020). Roles of individual differences and traffic environment factors on children's street-crossing behavior in a VR environment. *Injury Prevention, 26*(5), 417–423. https://doi.org/10.1136/injuryprev-2019-043268

Whitebread, D., & Neilson, K. (2000). The contribution of visual search strategies to the development of pedestrian skills by 4–11 year-old children. *British Journal of Educational Psychology, 70*(4), 539–557.

Young, S. L., Wogalter, M. S., & Brelsford, J. W., Jr. (1992). Relative contribution of likelihood and severity of injury to risk perceptions. *Proceedings of the Human Factors Society Annual Meeting*.

Zimmerman, P. H., Bolhuis, J. E., Willemsen, A., Meyer, E. S., & Noldus, L. P. (2009). The Observer XT: A tool for the integration and synchronization of multimodal signals. *Behavior Research Methods, 41*(3), 731–735. https://doi.org/10.3758/brm.41.3.731

Ole Johan Sando is an Associate professor employed at the Department of Physical Education and Health at Queen Maud University College of Early Childhood Education (QMUC) in Trondheim, Norway. His PhD work focused on how the physical environment in ECEC relates to children's well-being and level of physical activity. Ole Johan has previously researched how the safety focus in society affects children's opportunities for physically active play, injuries and accidents in ECEC and young children's outdoor activities.

Rasmus Kleppe is an Associate professor employed at the ECEC provider KANVAS and the Department of Physical Education and Health at Queen Maud University College of Early Childhood Education (QMUC). His PhD examined 1-3-year old's risky play in Early Childhood Education and Care settings. He has been involved in studies on quality in ECEC institutions and research on the role of the physical environment in ECEC institutions for children's play.

Ellen Beate Hansen Sandseter is a Professor in the Department of Physical Education and Health at Queen Maud University College of Early Childhood Education (QMUC) in Trondheim, Norway. Her primary research focus is on children's physical play, outdoor play, and risky/thrilling play among children in Early Childhood Education and Care (ECEC) institutions, as well as how to develop physical environments for children's play and learning. She has also been involved in research on Norwegian children's experiences of participation and well-being in Norwegian ECEC institutions, and projects about safety work, child injuries and injury prevention in Norwegian ECEC institutions. Keywords: early childhood education, play, risky play, play environements, well-being