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Perception of Affordance in Children and Adults While Crossing Road between Moving Vehicles

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Abstract

Road crossing is a perceptual-motor skill and becomes critical when to cross as a pedestrian. In the present study, we investigated gap affordance perception and crossing behavior of pedestrians when they crossed the gap between two vehicles. Children and young adults attempted to cross inter-vehicle gap while walking on a treadmill in a virtual environment. Participants crossed gaps between two vehicles facing various gap characteristics. We manipulated vehicle size, vehicle speed and gap time between two vehicles and examined participants' affordance of crossability evaluating transition points for different task constraints. Our results revealed that children had higher transition points than adults and crossability of both age groups influenced by gap characteristics. We conclude that children were more prone to unsafe crossings relative to adults and perception of affordance affected when the road-crossing environment become constrained.

Keywords

Pedestrian, Gap Affordance, Road Crossing, Perception-Action, Virtual Environment

1. Introduction

Road accidents are very common all over the world. Among OECD member countries, South Korea had the highest rate of per capita road fatalities (OECD, 2016). According to fatality statistic, the pedestrian was the most hazardous part (45%) of road deaths. Road fatality rate represents a compelling public health problem in South Korea. This phenomenon, therefore, has drawn the attention of researchers to investigate the factors associated with road fatalities. Misjudging the crossability for an inter-vehicle gap during road crossing can be dangerous for road users. We, therefore, focused to investigate the age-related differences between pedestrian children and young adults in perceiving affordance of crossability when to cross an inter-vehicle gap. Particularly, we analyzed the effects of gap characteristics on crossability of pedestrians in an interactive virtual environment.

Opposing to other simple everyday activities, crossing an inter-vehicle gap between moving traffic is incomparably a complex perceptual-motor task. Road crossing is a task requiring not only to make a judgement whether a gap between vehicles affords safe crossing, but also to coordinate self-locomotion through the chosen gap while avoiding collision with any moving vehicles. As such, one must identify crossability in terms of temporal gap between vehicles, and to synchronize one's movement in accordance with perceptual information. A gap affords to cross if the pedestrian's (estimated) crossing time is less than the temporal size of the gap (Lee, Young, & McLaughlin, 1984). This means that the selected gap must be sufficiently large to cross safely and should be chosen carefully according to individual's capability. Errors in perception of crossability and imprecise movement coordination endanger collisions. Our approach prospected these two components, i.e., perception of gap crossability constrains the action (crossing behavior) and action capabilities constrain the perception of affordable gap. Further, we discuss the task constraints on affordance perception and crossing behavior during walk to cross single lane of the road.

Past research has demonstrated that children are less efficient than adults in road-crossing task, either cyclist (Grechkin, Chihak, Cremer, Kearney, & Plumert, 2013; Plumert, Kearney, & Cremer, 2004, 2007), or pedestrian (Barton, Schwebel, & Morrongiello, 2007; Pitcairn & Edlmann, 2000; Simpson, Johnston, & Richardson, 2003; te Velde, van der Kamp, Barela, & Savelsbergh, 2005). Plumert and co-investigators (2004, 2007) examined how child and adult cyclist chose gaps when they crossed traffic-filled intersections in virtual environment. Both the studies showed that children were less skillful in initiating movement and took longer to cross the road. Grechkin and co-workers (2013) analyzed children and adults' gap selection decisions while cycling across two lanes of opposing traffic-road. Whereas aiming at pedestrian, Simpson and colleagues (2003) examined gap selection behavior of children and adults using a head mounted display in virtual reality system. The results showed that children had less number of safe crossings than adults. In the collision avoidance task, te Velde and co-researchers (2005) tested children and adults' adaptive behavior while crossing in front of a motorcycle. The results of that study also displayed that children delayed on the road curb before crossing than adults did.

In previous studies, different methods have been used to analyze road-crossing behavior of pedestrians, for example, pretend road tasks devised to study pedestrians' gap acceptance behavior in road crossing (Lee et al., 1984; Young & Lee, 1987); moving a doll across the roadway that resembled road crossing task was presented to participants (te Velde, Kamp, & Savelsbergh, 2008). Estimation tasks involved button pressing or verbal responses of participants to select crossable gaps within moving traffic (Connelly, Conaglen, Parsonson, & Isler, 1998; Oxley, Ihsen, Fildes, Charlton, & Day, 2005).

Nevertheless, the methods used by previous studies were problematic to compare results. Estimation tasks can be advantageous in terms of having no physical risks in them. However, the ecological validity of estimation tasks has been depreciated previously (e.g., Simpson et al., 2003). Further, estimation tasks were not similar and differed to actual road-crossing task (e.g., te Velde et al., 2005). Alternatively, actual walking allows the participants to readjust their perception and action in a reciprocal way. This perspective is promoted by ecological approach to perception and action (Gibson, 1986). Keeping in view this approach, visual timing and precision of actions are under the influence of task constraints (Fayt, Bootsma, Marteniuk, Mackenzie, & Laurent, 1997). Interceptive actions require the actor to calibrate perception and action keeping focus on moving object (Oudejans, Michaels, Bakker, & Dolné, 1996). Road crossing is also an interceptive action that involves actors to perceive affordance (crossability) and to coordinate movement according to task demands.

Although ample work has been done so far to explore the crossability of pedestrians, however, age-related differences between child and adult pedestrians on crossing decisions have not been studied previously (Oudejans, Michaels, van Dort, & Frissen, 1996). Further, the ecological validity of virtual reality systems used in previous studies was limited which constrained the perception-action calibration (e.g., Simpson et al., 2003). Furthermore, presenting the single vehicle or an object does not provide practical results and less applicable to the road crossing task because people face more than a single vehicle in real-world road crossing (e.g., te Velde et al., 2005). Moreover, the effects of task constraints on crossability of children and adults (pedestrian) have not been analyzed in previous literature. Thus, our goal was to investigate how affordance perception and crossing behavior constrained when road-crossing task altered.

In the present study, we focused on whether pedestrians' affordance changes over age and if crossability influenced by gap characteristics. Furthermore, we wanted to examine the effects of vehicle size and vehicle speed on pedestrian's crossability using an improved virtual reality system in actual walking set-up. Actual walking allows pedestrians the opportunity to calibrate perception and action. We hypothesized that crossability could be different for children and adults, and gap characteristics may influence the pedestrians' affordance of crossability.

2. Method

2.1. Participants

A total of 32 children and healthy young adults took part in the experiment. Sixteen children ((Mean age = 12.18 years, SD = 0.83), and 16 college students (Mean age = 22.75 years, SD = 2.56) participated with normal or corrected to normal vision. Child participants were recruited from a local elementary school and adults from the undergraduate students of Kunsan National University with informed consent. The participants were selected as a representative sample from the two target groups through nonprobability sampling method. All the participants performed the experiment on voluntary basis.

2.2. Apparatus

The experiment was conducted using a virtual reality walking simulator. The virtual reality system consisted of a PC Intel, an Oculus Rift (head mounted display), and a treadmill (0.76 m width, 1.26 m length, and 1.10 m height including frame). The treadmill was equipped with a hand grip, and a Velcro Belt attached on backside of it. A magnetic counter was attached with spinning ruler of the treadmill to record locomotion displacement data. Oculus Rift was interconnected with PC through DVI/HDMI cable. The virtual scene could be viewed through HMD, presenting participants with stereoscopic 3D visual imagery. The apparent motion through the visual scene and the motion of vehicles were smooth and visually continuous. The virtual environment consisted of a street road, trees, residential buildings, and the sky. The total road-width was 7 m that consisted 3.5 m width of each lane. The road lanes were divided by yellow lines and crossing path of pedestrian was indicated by white lines across the road. We presented two vehicles on the near lane of the road, the second lane was empty during experiment. Vehicles were presented on the virtual road from left side and approaching vehicles can be viewed through displays of HMD. There were two types of vehicles in the experimental set up i.e., car and bus. A car was 1.5 m in width and 4.5 m in length, and a bus was 2.5 m in width and 11 m in length.

2.3. Design and Procedure

After arriving at the laboratory, the participants were given verbal instructions about the experimental task. The experimenter told the participants that they would be crossing a street road between two vehicles in virtual environment, and instructed that walk as though they were walking in a real-world environment. Following instructions, the experiment started with a familiarization session that was designed to make participants aware of the task and the virtual environment. During the familiarization period, participants were given warm-up practice for 5 minutes walking on treadmill without head mounted display (HMD). After the warm-up, one of the experimenters helped the participant to wear HMD and each participant was given 3 trials without any traffic on the virtual road. Next were the practice trials with traffic in which participant was reminded that "when the experimenter say 'ready-go' upon the given trial, you have to look left to see approaching vehicles before start walking to cross the road. Upon a given trial, experimenter waited a few seconds to make sure if the virtual scene is calibrated and smoothly visible to the participant. The vehicles were presented to the near lane of the road and approached from participant's left sideway. In the practice period, 3 trials were presented at the speed of 25 km/h and 70 km/h and repeated if the participant was not fully familiar with the task. Following familiarization session, participants were presented experimental test trials.

Pedestrian's initial distance was 3.5 m starting from the road curb. We manipulated temporal gaps between two vehicles (2.5, 3, 4 s for adults and 3, 4, 5 s for children). The temporal gaps between vehicles were defined as the difference between the time at rear-bumper of lead vehicles reached the crossing line and the time at which front bumper of the second vehicle reached the crossing line. We set the time gap between two vehicles in such a way that center-of-the-gap (CG) would arrive within 4 s at the contact point (CP) after initiating a trial. The same type of vehicles used in each trial, namely, 2 cars or 2 buses respectively that means we did not present car and bus together in any of the trials. The vehicles moved with the speed of 30 km/h or 60 km/h respectively. We varied temporal gaps between two vehicles, vehicle type, and vehicle speed. This combination of 3 temporal gaps, 2 vehicle types and 2 vehicle speeds resulted in a total of 12 experimental conditions. Thus, each participant completed a total of twelve test trials. The order of test trials was random and varied across participants.

2.4. Data Analysis

The coordinates of pedestrian and vehicles were recorded by the simulation at every time step. Three basic time functions were automatically established on every accepted crossing: 1) the reaching time of the pedestrian on the other end of the road-lane starting from road-curb, 2) the reaching time of the lead vehicle at the crossing line, 3) the reaching time of the rear vehicle at the crossing line. All the trials were coded as either success, collision, or fail by the simulation. If the pedestrian reached the other side of the road (curb) without collision, it was coded as a success. If at a given trial pedestrian was collided by lead or rear vehicle, it was coded as a collision. A trial was regarded as a fail when a pedestrian missed any of the three gaps. We entered all individuals' raw data into a LabVIEW software (version 8.9) to compute respective time of pedestrians and vehicles. Further, we computed the following dependent variables from the data.

2.4.1. Transition Points and Thresholds

We assessed transition points for children and adults depending on the percentage of safe and unsafe crossings. We categorized safe and unsafe crossings based on safety margins (Safety margin would be described in the next section). Safe crossing considered when the participant had safety margin more than 1.5 s and unsafe crossings defined as when participant had safety margin less than 1.5 s (cf., Simpson et al., 2003). Transition points and thresholds were calculated using a logistic regression analysis on recorded data. The following logistic function was applied to figure out the transition point between unsafe and safe crossings:

$$F(x) = 1\Big/\left(1 + \mathrm{e}^{(-((x-\alpha)/\beta))}\right)$$

where x is the time gap and β is the slope of the logistic curve at point α. This function defined the transition points and thresholds. The transition points indicated the points at which participants' crossing behavior change from not safe to safe crossings. (i.e., the point at which probability of safe crossings was 50%, $p = 0.5$), and the transition thresholds (which correspond to half the difference between the function values of 0.25 and 0.75) pointed out the abruptness of the transition, and whether the perception of crossability was precise.

2.4.2. Crossing Behavior

In the first step, we computed safety margins (SM) depending on pedestrian's crossing time and reaching time of the rear vehicle. SM was the difference between pedestrian's crossing time and reaching time of the rear vehicle to crossing line (SM = CTR − PCT). PCT was defined as the time at which pedestrian cleared the crossing line before vehicle (starting from the road curb to the point where the first lane of the road ends). CTR was defined as the time at which the front bumper of rear vehicle reached the pedestrian crossing line.

Following, based on safety margins, we categorized participants' crossing behavior on all accepted crossings. A success was considered if the safety margin was more than 1.5 s. A tight fit was regarded if there was SM between 0 and 1.5 s (cf. Simpson et al., 2003). The safety margin was 0 when a collision occurred and SM was minus for failed crossings. We performed data analysis into three steps i.e., crossing thresholds using logistic regression analysis, crossing behavior using analysis of variance, and percentage of safe and unsafe crossings using a chi-square test. The level of significance was set at 0.05 for all statistical analysis on dependent variables.

3. Results

3.1. Transition Points and Thresholds

The participants' crossing responses were plotted as a function of age, vehicle size, and vehicle speed. We computed critical points for children and young adults where transition changes from not safe to safe crossing. Logistic regression analysis showed that children's transition point occurred at 3.09 s and for adults at 2.78 s (**Figure 1**).

Overall children's transition point from not safe to safe crossing was higher than that of young adults. As we expected, the transition from not safe to safe crossings also changed by vehicle speed and size. When vehicles traveled at 30 km/h the transition points occurred at 2.98 s and 2.69 s for children and young adults respectively. On the other hand, when vehicles traveled at 60 km/h the transition points resulted at 3.31 s and 2.93 s for children and young adults respectively. The transition points for children were higher relative to young adults at both speeds.

While vehicle size results showed that the transition points of children resulted at 3.03 s and 3.23 s for car and bus respectively. The transition point of young adults occurred at 2.70 s and 2.91 s for car and bus respectively. These results indicate that transition points were slightly lower for car than bus and transition thresholds of children were more abrupt than adults for both vehicle size and speed. The transition points and thresholds for children than young

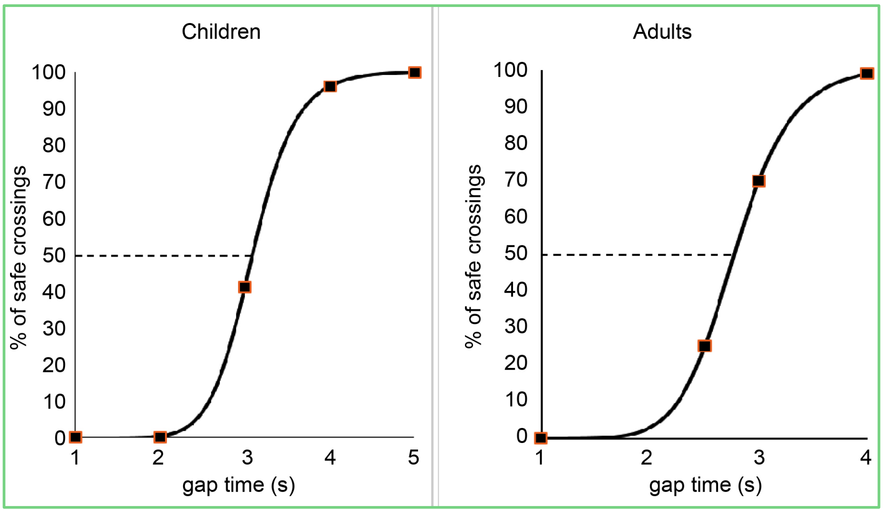

Figure 1. Percentage of safe crossing for children and adults as a function of age and gap time. Note that these were the combined percentages of vehicle speed and vehicle size for both age groups.

adults at both vehicle speeds and vehicle type were shown in Table 1.

3.2. Crossing Behavior

2 age (children, adults) × 2 speed (30 km, 60 km) × 2 vehicle types (car, bus) repeated measures ANOVA on safety margin showed a main effect of age ($F(1, 27) = 4.51$, $p < 0.04$), vehicle type ($F(1, 27) = 48.90$, $p < 0.0001$), and vehicle speed ($F(1, 27) = 6.59$, $p < 0.01$). Children's safety margin (2.18 ± 0.36) was significantly less than young adults (2.23 ± 0.48).

In addition, vehicle size and vehicle speed interaction was significant ($F(1, 27) = 6.41$, $p < 0.01$). Post-hoc analysis showed that participants safety margins were less at vehicle speed 60 km/h (2.12 ± 0.41) than 30 km/h (2.34 ± 0.46) when they crossed before the car.

3.3. Unsafe Crossings

Frequency analysis showed that the number of children's unsafe crossings (41) was higher than that of adults (22). From the total of trials, children's unsafe crossings were a collision (0.80%), 6 fails (4.83%), and 34 tight fits (27.41%). In contrast, adults' unsafe crossings were a collision (0.79%), a fail (0.79%), and 20 tight fits (15.87%).

A chi-squired analysis showed that percentage of unsafe crossings for children (33.06%) was significantly higher than percentage of adults' unsafe crossings (17.46), $\chi^2 = 8.07$, $p = 0.0045$.

Further, percentage of unsafe crossings for children (48.39%) was significantly higher than that of adults (13.33%) when they crossed before car with a velocity of 60 km/h ($\chi^2 = 8.73$, $p = 0.003$). Additionally, children's percentage was significantly higher (41.94%) relative to adults (9.39%) when they crossed before bus with a velocity of 30 km/h ($\chi^2 = 8.81$, $p = 0.003$).

Table 1. Transition points and thresholds for children and young adults as a function of age, vehicle size and vehicle speed).

	Age		Transition Points (s)				Transition Thresholds (s)	
	Car	Bus	30 km/h	60 km/h	Car	Bus	30 km/h	60 km/h
Children	3.03	3.23	2.98	3.31	0.7	0.83	0.72	0.82
Adults	2.70	2.91	2.69	2.93	0.54	0.55	0.56	0.53

Transition points were the points at which the probability of safe crossing was 0.5.

4. Discussion

The aim of this paper was to examine the age-related differences between children and adults regarding affordance of crossability. The results of this study clearly showed that transition points were higher for children relative to adults. The higher transition points displayed more probability of unsafe crossings for children than that of adults. The transition points happened at higher level for children when incidence of unsafe crossings increased. While evaluating behavior on the accepted crossings, children ended up with less safety margin relative to adults. Apparently, this discrepancy emerged because of developmental differences between children and adults. It seemed as if children misjudge the affordance of the gap to cross and their locomotion took longer to clear the roadway. This discrepancy of judgment and motorability between children and adults is consistent with the previous research on child cyclists' perception of affordance (Plumert et al., 2004) and is compatible with the concept that children make errors in perceiving affordances which might be a cause of childhood injuries (Plumert, 1995).

The possible reasons behind this mismatch of performance might be described in a way that children underestimate arrival time of vehicle on the crossing path. However, the previous study on cyclists (Plumert et al., 2004) suggested that children did not differ in perceiving the time to contact and chose same temporal gaps as adults did. Further research is still needed to determine the accuracy of time to contact estimates between pedestrian children and adults by manipulating time to arrival of vehicles. Another possible reason might be that children overestimated their ability to clear the roadway. Referring the cyclists again, children delayed in getting the bicycle started that resulted in more time than assumed to reach the other curb of the road. Together, this description is compatible with the idea that children overestimated their physical abilities and pruned to risk for injuries (Schwebel & Plumert, 1999).

In addition, we intended to examine the effects of vehicle size and vehicle speed on the affordance of crossability. Our vehicle-related results also indicate that crossability of both age groups influenced by vehicle speed and vehicle size. Considering the effects of vehicle size, our results showed a drop in the probability of safe crossing when participants crossed road between two buses than when crossing between two cars. These results indicating the size of approaching vehicle influence the crossability of pedestrians. Our results regarding effects of vehicle size confirm the proposition of the previous review that perceptual judgments could be interrupted by approaching vehicle size (DeLucia, 2013).

On the other hand, effects of vehicle speed on crossing behavior also showed that the probability of safe crossing dropped when speed increased. Higher transition points with speed increment emerged when there were more unsafe crossings. These findings are again confirming to the work of previous research that vehicle speed has impact on judging crossable gap in estimation road-crossing task (Connelly et al., 1998). Our findings, however, were different in three ways. First, we analyzed affordance of crossability in child pedestrians and adults that was not investigated previously. Second, we allowed participants to walk through the gap instead of perceptual judgements whereas most of the previous studies examined crossing decisions of children (e.g., Connelly et al., 1998; Pitcairn et al., 2000; Lee et al., 1984). Third, our experimental protocol provides more accurate data about pedestrian's road-crossing behavior. While taking steps in actual walking, participant had opportunity to perceptually judge and scale their movement accordingly. Specifically, when an actor has proceeded an action in an environment, the consequences of that action provides more information to the actor (Gibson, 2000).

Furthermore, virtual reality (e.g., Oculus Rift) is a beneficial tool to study human behavior because this kind of tools has not physical risks for participants as people have in the real-world road crossing. Another benefit of using virtual reality is that researchers have experimental control over these tools providing sameness as a real behavior. It has also been demonstrated in a previous study that perception and action calibration improved in case of an interactive road-crossing compared to estimation task (te Velde et al., 2005). A question raised by analysts is that virtual reality environment has limited physical fidelity (Stoffregen, Bardy, Smart, & Pagulayan, 2003). Considering this argument, it can be assumed that participants might have acted differently in case of actual road-crossing between traffic. If this so, there could have higher number of collision in absence of risk due to feeling safe in virtual environment. In contrast, our results indicated that participants had very low number of collisions (n = 2 total, one by children and one by adults). While previous studies found larger number of collisions with limited fidelity even at lower speed (e.g., Simpson et al., 2003). This less number of collisions confirmed the idea that participants could calibrate to perception-action and behaved like walking in a real environment when they crossed gap in the virtual environment.

Our results supported the improved validity of virtual reality, however, walking on treadmill might create some limitation on walkability due to friction of moving belt. It is, therefore, suggested that removal of these limitations for walkability using actual walk settings in virtual environment and manipulation of gap characteristics is still needful and recommended for future research.

5. Conclusion

The present study addressed age-related differences between pedestrian children and young adults in road-crossing task, and the effects of gap characteristics on road-crossing behavior. Children took longer to cross the time gap and ended up with less safety margins than adults did. Further, children were more likely to have problems when the speed of vehicles was faster and vehicle size became larger. It is concluded that children's affordance of crossability deviates from adults because of perceptual-motor differences between the two age groups. Our conclusion can be supported by the suggestion that perception-action skills improve with age (Plumert & Kearney, 2014). In addition, our findings advocate that children are less accurate in perceiving the gap affordance when the crossing environment becomes demanding. The results of our study can be applicable to counter child pedestrian safety issues and in development of training programs.

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