Published in final edited form as:

Child Dev Perspect. 2014 December 1; 8(4): 207–212. doi:10.1111/cdep.12089.

How Do Children Perceive and Act on Dynamic Affordances in Crossing Traffic-Filled Roads?

Jodie M. Plumert [Professor of Psychology] and **Joseph K. Kearney [Professor of Computer Science]**

The University of Iowa

Abstract

Successfully perceiving and acting on dynamic affordances is critical for children and adults to function. In our work, we look at how children cross roads as a model for understanding how they learn to perceive and act on dynamic affordances. Ten- to 14-year-old children and adults ride an interactive bicycling simulator through an immersive virtual environment where they cross intersections with continuous cross traffic. We consistently find developmental and individual differences in children's ability to tightly time their entry into the roadway relative to the lead car in the gap. Given that children do not adjust their gap choices to match their less precise timing abilities, children take more risks when crossing roads than adults. We conclude by discussing possible reasons for these developmental differences in movement timing.

Keywords

perception-action development; *dynamic affordances*; *road crossing*; *bicycling*

Moving oneself in relation to other moving objects is critical for adaptive functioning. This can involve either avoiding other moving objects (e.g., crossing a street) or contacting other moving objects (e.g., stepping onto an escalator). A critical aspect of moving successfully in relation to other moving objects is accurately perceiving affordances, or possibilities for action that depend on the relationship between the characteristics of the perceiver and the properties of the environment (Gibson, 1979). This involves deciding what actions to take (e.g., which moving stair should I step onto?) and determining when and how to act on those decisions (e.g., when should I start moving, how fast should I move?).

Perceiving affordances is more complex when objects are moving than when they are stationary because affordances change over time when objects are moving. Actions that are possible at one moment may not be possible a short time later. We consider these time-varying possibilities for action as dynamic affordances (see also Fajen, 2013). This contrasts with static affordances in which the timing of movement has no impact on either judging or acting on the affordance (e.g., judging the reachability of an object on a shelf). Typically, dynamic affordances involve self and object movement, as when a batter decides whether

Correspondence concerning this article should be addressed to Jodie M. Plumert, Department of Psychology, University of Iowa, 11 SSH East, Iowa City, IA 52242; jodie-plumert@uiowa.edu..

(and when) to swing at a pitch. Dynamic affordances can also involve other changes over time (i.e., movements), such as a drummer attempting to join the rhythm on the downbeat.

Perceiving dynamic affordances becomes challenging when perceivers must choose a possible action from a temporal stream of possibilities. For example, when crossing a street, gaps of varying temporal sizes are embedded in a continuous stream of traffic, requiring perceivers to shift their attention quickly from one gap to the next as they evaluate the sequence of affordances. Acting on dynamic affordances is also more complex than acting on static affordances because perceivers often must time their movements precisely. For example, moving too soon or too late when crossing a street can result in a collision with a vehicle.

Children's Road Crossing

In our work, we use crossing roads as a representative task for studying how children learn to perceive dynamic affordances. Road crossing is a common yet potentially dangerous activity for children and adults alike. As noted earlier, road crossing is also a good model for studying time-varying affordances because it involves deciding among many possibilities for action embedded in a continuous stream of moving objects (see also Grechkin, Plumert, & Kearney, 2014). These tasks contrast with other tasks used to study dynamic affordances in which participants have to make judgments and coordinate actions with a singular event, such as attempting to intercept a single target (e.g., Fajen & Warren, 2007). While useful for isolating components of dynamic affordances (e.g., decisions versus actions), such tasks eliminate two key characteristics of dynamic affordances: directing attention to assess the changing possibilities for action and selecting an appropriate opportunity for action.

We seek to bring together basic and applied issues into a single program of research (Plumert, Kearney, & Cremer, 2007; Schwebel, Plumert, & Pick, 2000). On the basic side, our research seeks to answer questions about the development of perception-action skills. We want to understand how decisions and actions about dynamic affordances become tuned more finely over the short-term scale of learning and the longer-term scale of development. On the applied side, our research seeks to determine how immature perception-action skills contribute to bicycling injuries and fatalities in children. Collisions between motor vehicles and cyclists are a common cause of severe injuries in childhood and adolescence: In 2012, 10,000 children ages 5 to 15 were injured in such collisions (National Highway Traffic Safety Administration, 2012), with many collisions occurring at intersections (Wang & Nihan, 2004). The dual focus of our research has enriched our understanding of both the development of perception-action skills and risk factors for car-bicycle collisions.

Road crossing is a complex perception-action task with two critical components: selecting a gap in traffic that affords crossing and coordinating movement through the gap. A gap affords crossing if the individual's (projected) crossing time is less than the temporal size of the gap (Lee, Young, & McLaughlin, 1984). To coordinate movement through the gap successfully, individuals must cut in closely behind the lead vehicle in the gap while crossing before the tail vehicle reaches their line of travel. Given the dynamic nature of traffic, gap decisions and crossing movements must be tightly linked. Selecting a gap that affords crossing can lead to harmful outcomes if the individual waits too long before moving, and coordinating movement precisely can also lead to harmful outcomes if the individual selects a gap that is too small to afford safe crossing.

The Bicycling Simulator

In our work, we use a real-time bicycling simulator (see Figure 1A). A bicycle is mounted on a rigid frame that sits in the middle of three large display screens placed at right angles relative to one another. The bicycle is instrumented to sense the steering angle and rear wheel speed. Steering angle and wheel speed data are combined with virtual terrain information to render real-time graphics corresponding to the rider's path through the virtual environment. The rear wheel is connected to a torque motor, which generates an appropriate dynamic force to account for rider and bicycle mass and inertia, along with simulated terrain slope, ground friction, and air resistance. The result is a riding experience that incorporates realistically many of the dynamics of bicycling on streets.

Participants ride the bicycle through a virtual environment consisting of a straight, residential street with 12 intersections. In the basic road-crossing task, participants face either a single lane or two lanes of continuous cross traffic (which is going at 25 or 35 miles per hour) at each intersection, with varying temporal gaps between cars (see Figure 1B). The bicyclists' task is to cross the intersections without getting "hit" by a car. The primary measures of interest are gap choices and movement timing (i.e., timing of entry relative to the lead car and time left to spare relative to the tail car).

Crossing Continuous Traffic at Intersections

Our focus is on understanding developmental and individual differences in bicyclists crossing intersections with continuous cross traffic. We started with the simplest case in which the cross traffic was restricted to the near lane of traffic, with randomly ordered gaps of varying sizes (Plumert, Kearney, & Cremer, 2004). Ten- and 12-year-old children and adults chose the same size gaps. Nevertheless, children ended up with less time to spare when they cleared the path of the approaching car because they waited longer than adults to start crossing. This resulted in less time to spare when children cleared the path of the approaching car. This delay in starting to move is consistent with other work showing that while walking, children are slower to start to cross a road (Barton & Schwebel, 2007; Lee et al., 1984; Pitcairn & Edelmann, 2000; te Velde et al., 2005).

We have also examined how children and adults cross a single lane of high-density traffic (Plumert et al., 2011) with an eye to how high-density traffic affects gap choices and movement timing, and how experience with the task leads to change in gap choices and movement timing. Ten- and 12-year-old children and adults crossed 12 intersections with continuous cross traffic coming from their left-hand side. In the control condition, participants encountered normal-density traffic at all intersections. In the high-density condition, participants encountered a set of four intersections with high-density traffic sandwiched between two sets of four intersections with normal-density traffic.

Again, we found no age differences in gap choices, but significant age differences in time to spare. Consistent with research on pedestrians (Guth et al., 2005), both children and adults took much smaller gaps when faced with high-density than with normal-density traffic. They also cut in more closely behind the lead car in the gap when crossing the high-density intersections, suggesting that both children and adults adjusted their actions to match their (risky) decisions more closely. However, children were also "hit" at 20 percent of high-density intersections, indicating that although they attempted to coordinate their actions more closely with their decisions, they were often unsuccessful at doing so. We also found that after experience with high-density traffic, both children and adults continued to take tighter gaps at later intersections with lower-density traffic.

Experience with the road-crossing task also improved 10-year-olds' movement timing across the session in both the high-density and control conditions. Across the session, 10-year-olds cut in closer behind the lead car and crossed the intersection more quickly. As a result, they also improved their safety margins by 25 percent by the last set of intersections. In contrast, 12-year-olds and adults showed almost no change in time to spare across the session. These types of gains in movement timing over the short term may help produce the developmental changes seen over the longer term.

We have also examined how children and adults choose gaps and time movement when crossing two lanes of opposing cross traffic (Grechkin, Chihak, Cremer, Kearney, & Plumert, 2013). Judging gap affordances when crossing two lanes of opposing cross traffic is challenging given that the gaps approach from opposite directions and cannot be observed simultaneously. For a pair of near- and far-lane gaps to afford safe crossing, each individual gap must be large enough to allow safe crossing and the two gaps must overlap sufficiently to allow safe crossing. The relationship between the opening of the near and the far gaps provides riders with two qualitatively different opportunities for crossing. When the far gap opens before or with the near gap, the temporal crossing interval when both lanes are clear of vehicles appears as an aligned gap pair spanning both lanes of traffic. Conversely, in a rolling gap pair, the near-lane gap opens before the far-lane gap. If the temporal offset is large enough, the cyclist can enter the near-lane gap before the far-lane gap opens, allowing the rider to cut in closely behind the lead car in the far-lane gap.

In contrast to our earlier work on the single-lane road crossing, this condition produced significant developmental differences in gap selection. Although 12- and 14-year-olds and adults preferred rolling over aligned gap pairs, this preference was stronger for adults. This is consistent with research with pedestrians (Barton & Schwebel, 2007) in which adults were more likely than children to enter the near lane before the far lane was open completely. All age groups showed similar preferences for the near-lane gap sizes, but children made some risky choices when selecting a far-lane gap. Children were also less skillful than adults in timing their crossings. Twelve- and 14-year-olds delayed significantly their entry into both the near lane and the far lane compared to adults. The less skillful timing combined with the risky gap choices resulted in significantly smaller observed margins of safety for children than for adults.

Intercepting Moving Gaps on the Run

We have also examined developmental differences in movement coordination skills using a gap-interception task that requires riders to intercept a moving gap on the run (Chihak et al., 2010, 2014). This task allows us to study synchronization of self and object movement independent of movement initiation and gap-selection factors (see also Louveton et al., 2012a, 2012b). Our initial study examined how well 10- and 12-year-old children and adults adjust their movement to intercept a moving gap (Chihak et al., 2010). At each intersection, riders attempted to pass without stopping between two red blocks moving from left to right (see Figure 2). Block motions were timed so participants needed to speed up or slow down to intercept the gap. As in our road-crossing studies, children delayed their entry into the gap relative to adults and as a consequence, had less time to spare than adults when they intercepted the target blocks. Children were more variable in their approach to the intersection and in the amount of time they had to spare. Thus, even though children did not have to select the gap to cross or initiate movement from a stop, they still timed their movements less skillfully than adults.

We used the gap-interception task to address the question of how interceptive actions become more finely tuned with experience (Chihak et al., 2014). Adults exhibit more finely tuned interception skills with practice, even over relatively short periods (Camachon et al., 2007; Montagne et al., 2003), and variable practice is more beneficial than consistent practice (Huet et al., 2011). We examined how consistent versus variable practice with speeding up or slowing down to intercept the blocks affected 10-year-olds' performance on the interception task. The block timings were adjusted so participants were required to speed up on all trials (speed-up condition), slow down on all trials (slow-down condition), or speed up on some trials and slow down on other trials (variable condition).

Children who experienced both slow-down and speed-up trials appeared to use a split-the-difference approach whereby they averaged their previous experience with the two trial types. This was beneficial in the slow-down trials but detrimental in the speed-up trials. On slow-down trials, 10-year-olds in the variable condition slowed down far less than 10-year-olds in the slow-down condition, whereas on the speed-up trials, 10-year-olds in the variable condition sped up less than 10-year-olds in the speed-up condition. As a consequence, children in the variable condition required less speed correction to intercept the gap on slow-down trials and more speed correction on speed-up trials. Adults timed their interceptive actions precisely regardless of the condition. These findings suggest that children may have more difficulty than adults integrating their past experience with online information to coordinate self and object movement.

Timing Is (Almost) Everything

Our research has revealed systematic developmental and individual differences in how children time their movement relative to the lead car in the gap. Given that the lead vehicle in the gap acts as a gate to crossing, keying movement relative to the lead vehicle is critical for tightly synchronizing self and object movement. We find consistently that 10- to 14-year-olds time their movement relative to the lead vehicle less tightly than adults, both in the road-crossing task and in the interception task. These difficulties in timing movement relative to the lead car when entering the roadway almost always result in less time to spare relative to the tail car when exiting the roadway. Given that children do not adjust their gap choices to match their timing skills, children engage in riskier road-crossing behavior than adults.

Why do children time their movement less tightly than adults? One possibility is that children leave a larger berth intentionally because they are taught not to cross roads until the lead car has passed their line of travel completely. However, one might also expect that this kind of caution would be accompanied by choosing larger gaps . As noted earlier, we do not see children taking larger gaps than adults, even though these larger gaps are readily available. Another possibility is that children are less adept at starting their motion and hence, take longer to get moving once they have decided to cross. Ten-year-olds who have more inhibitory control time their entry more effectively (and have more time to spare) than their counterparts with less inhibitory control (Stevens, Plumert, Cremer, & Kearney, 2013). The ability to tightly coordinate self and object movement may be related to inhibitory control because it requires more self regulation—the rider must not begin to move too soon or too late. Moreover, the rider must begin to move based on the anticipated position of the car relative to the path of the bike, a skill that is likely to require more prospective control over movement (von Hofsten, 2007).

Yet another possibility is that children leave a larger berth between themselves and the lead vehicle (or block) because their timing is more variable. Across the board, children's performance is more variable than adults' performance. As a consequence, even if two riders aim for the same temporal point in a gap, the rider with more variability in timing will have a greater risk of colliding with the lead vehicle in the gap (see Figure 3). Given more variability in timing, it makes sense to aim for a later time of entry to avoid a collision with the lead vehicle in the gap. Of course, if children leave a wider berth between themselves and the lead vehicle in the gap to account for their greater variability in timing, then they should also choose larger gaps to give themselves more time relative to the tail vehicle in the gap. Their failure to do so suggests that children are not taking into full account their less precise timing skills when choosing gaps.

Finally, what information do riders use to evaluate and select gaps for safe crossing? Do they perceive the gap directly or do they use the temporal and spatial positions of the lead and tail vehicles to construct the gap? Both the gap and vehicles that define the gap boundaries matter for performance in an interception task (Louveton et al., 2012b). However, gap-interception tasks (Chihak et al., 2010, 2014; Louveton et al., 2012a, 2012b) do not tell us what information perceivers use when deciding about opportunities for action that are embedded in a stream of possible opportunities. Researchers could address this question by examining eye movements to determine how riders modulate their attention as they assess the crossability of approaching gaps.

Conclusions

Our research on children's road-crossing skills as cyclists has informed our understanding of both basic and applied research issues. With respect to basic issues, our research shows that perception-action skills undergo a prolonged period of development, particularly when the task involves moving oneself in relation to other fast-moving objects in the environment (Plumert et al., 2007). Furthermore, the fact that even 14-year-olds are less skilled than adults suggests that extensive experience with moving oneself in relation to other fast-moving objects is critical for fine tuning perception of dynamic affordances (see also Adolph, 2008). With respect to applied issues, our research shows that 10- to 14-year-old cyclists engage in riskier road-crossing behavior than adults, largely because their gap decisions and crossing movements are less tightly linked. This pattern is even more pronounced in children with less inhibitory control. Although both children and adults likely take larger gaps in the real world than in the virtual environment, we expect that the relative differences in movement timing that we see between children and adults also exist in real-world bicycling. As such, immature movement timing skills may be an important risk factor for collisions with motor vehicles.

Acknowledgments

This research was supported by grants from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (R01-HD052875), the National Science Foundation (IIS 00-02535, EIA-0130864, CNS-0750677), and the National Center for Injury Prevention and Control/Centers for Disease Control and Prevention (R49/CCR721682, R49/CE001167).

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Figure 1A (left) and 1B (right).

Photographs of the bicycling simulator. The visual angles are correct from the viewpoint of the rider in Figure 1A.

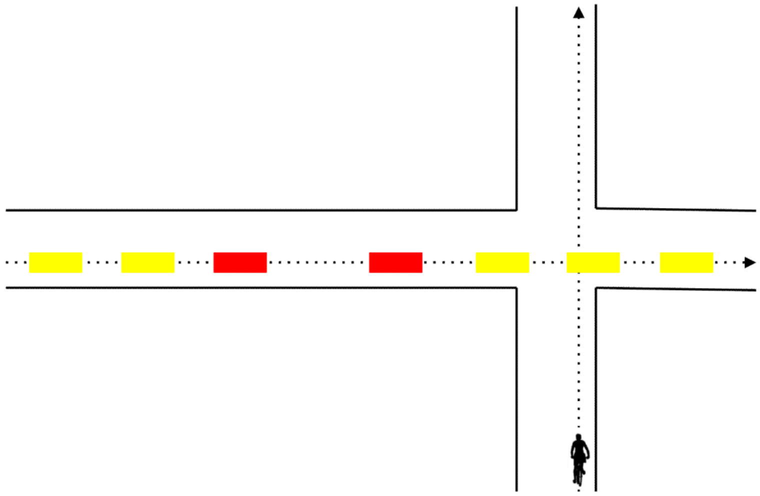

Figure 2. Schematic representation of the gap interception task

The dotted lines represent the direction of travel of the blocks and the rider. The task for the rider is to intercept the gap between the two red blocks without stopping.

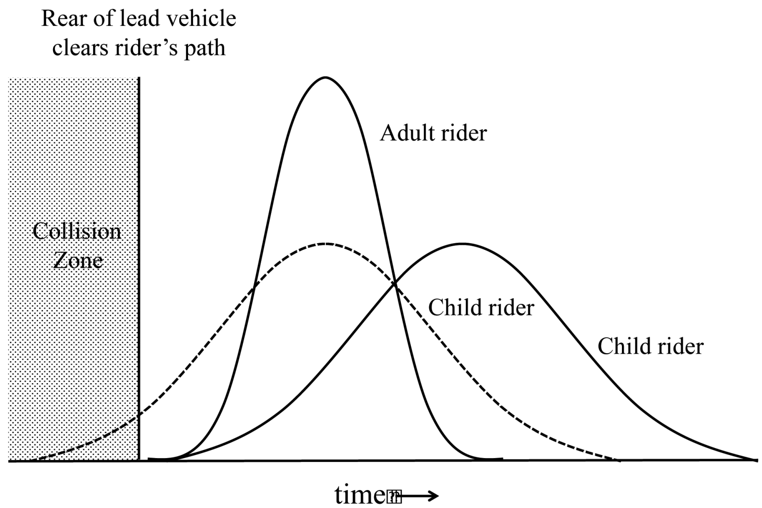

Figure 3.

Hypothesized impact of variability of entry times on the risk of colliding with lead vehicle. The curves show the distribution of entry times for adult and child riders. The area to the left of the time when the rear of the lead vehicle clears the rider's path shows collisions with the lead vehicle. The solid lines show the typical entry times for child and adult riders. The dotted line shows a child rider's risk of colliding with the lead vehicle if child and adult riders aimed for the same entry time.