Published in final edited form as:
Ecol Psychol. 2014 January 1; 26(1-2): 125–133. doi:10.1080/10407413.2014.874933.

Linking Decisions and Actions in Dynamic Environments: How Child and Adult Cyclists Cross Roads With Traffic

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Abstract

Unlike affordances involving stationary objects, affordances involving moving objects change over time. This means that actions must be tightly linked to decisions, making perceiving and acting on affordances involving moving objects challenging for children and adults alike. Here, we overview our program of research on how children and adults perceive and act on moving objects in the context of bicycling across roads in an immersive virtual environment. This work shows that although children attempt to adjust their actions to fit their risky decisions, they do not fully adjust their decisions to fit their action capabilities. This mismatch between child cyclists' decisions and actions may be a risk factor for car-bicycle collisions in late childhood and early adolescence.

Adaptive behavior within the environment involves perceiving affordances, or possibilities for action that depend on the fit between the characteristics of the perceiver and the properties of the environment (J. J. Gibson, 1979). When deciding whether it is possible to jump across a creek, for example, children must take into account the distance from one side of the creek to the other in relation to how far they can jump. Likewise, when deciding whether it is possible to catch a fly ball, children must take into account the trajectory of the ball in relation to how fast they can move. Errors in judging possibilities for action can occur when children misperceive their own level of ability or the properties of the environment (or both).

To date, much of what we know about how children perceive and act on affordances involves possibilities for action in static environments (i.e., moving oneself in relation to stationary objects and surfaces; Adolph, 1995; Franchek & Adolph, in press; McKenzie & Forbes, 1992: Plumert, 1995; Pufall & Dunbar, 1992). We know relatively little about how children perceive and act on affordances in dynamic environments (i.e., moving oneself in relation to other moving objects or surfaces; Lee, Young, & McLaughlin, 1984; te Velde, van der Kamp, Barela, & Savelsbergh, 2005).

Perceiving and acting on affordances is usually much more complex when objects are moving than when they are stationary. In large part, this is because affordances change over time when objects are moving. This means that a moving object may afford a possibility for action at one point in time but not at a later point in time. For example, a fly ball may be

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catchable if the person starts to move soon after the ball is hit, but not if the person waits to move until well after the ball is hit (Peper et al., 1994). In short, decisions and actions must be tightly linked to successfully realize affordances involving moving objects, particularly when the temporal window for movement is small. This means that actions must be fitted to decisions both spatially and temporally. This is not the case when perceiving and acting on affordances in a static environment. That is, the affordance remains the same regardless of when the person begins to move.

Road crossing is a common, everyday task that involves perceiving and acting on affordances involving moving objects. To successfully select a gap that affords crossing, individuals must accurately judge the temporal size of the gap in relation to the time required to cross the gap. This is further complicated by the fact that streams of traffic usually require individuals to evaluate multiple opportunities for crossing, sometimes involving more than one lane of traffic. To successfully act on a gap decision, individuals must synchronize their movements with respect to the lead vehicle in the gap in order to cross before the tail vehicle arrives. When there is more than one lane of traffic, individuals must also coordinate their actions with respect to multiple lead vehicles. Importantly, given the dynamic nature of traffic, gap decisions and crossing movements must be tightly linked. That is, selecting a gap that affords crossing can lead to poor outcomes if the child delays too long before moving, and precisely coordinating movement can also lead to poor outcomes if the child selects a gap that is too small to afford safe crossing.

Here, we overview our work on how children and adults perceive and act on affordances involving moving objects in the context of a real-world problem – bicycling across gaps in traffic. Throughout all of this work, we have attempted to bridge basic research on perception and action and applied research on childhood safety (Schwebel, Plumert, & Pick, 2000). Our focus is on children between the ages of 10 and 14 because children in this age range are at highest risk for car-bicycle collisions (National Highway Traffic Safety Administration, 2009).

The Bicycling Simulator

We have systematically investigated how child and adult cyclists link gap decisions and crossing actions using an immersive, interactive bicycling simulator (Babu et al., 2011; Chihak et al., 2010; Grechkin et al., 2013; Plumert et al., 2004, 2007; Plumert, Kearney, Cremer, Recker, & Strutt, 2011; Stevens, Plumert, Cremer, & Kearney, in press). The bicycling simulator consists of an actual bike mounted on a stationary frame that sits inside three large display screens placed at right angles relative to one another, forming a three-walled room (Figures 1a and 1b). The bicycle is instrumented to record the steering angle of the front wheel and the speed of the rear wheel. Steering angle and wheel speed measures are combined with virtual terrain information to render in real time the graphics corresponding to the rider's trajectory through the virtual environment. The rear wheel is connected to a torque motor, which generates an appropriate dynamic force taking into account rider and bicycle mass and inertia, virtual terrain slope, ground friction, and air resistance. This provides for a riding experience that realistically incorporates many of the real-world dynamics of bicycling.

Linking Decisions and Actions When Crossing a Single Lane of Traffic

Our initial work focused on the problem of how child and adult cyclists cross a single lane of traffic restricted to the near lane (Plumert et al., 2004). Ten- and 12-year-olds and adults rode the bicycling simulator through a virtual environment consisting of a straight, residential street with multiple intersections. Participants faced continuous cross traffic coming from the left-hand side, consisting of randomly ordered temporal gaps (some crossable and some uncrossable) between cars. Their task was to cross the intersections without getting “hit” by a car. We found that children and adults chose the same size gaps and yet children ended up with less time to spare when they cleared the path of the approaching car. When we looked back at what the children and adults were doing when they initiated their movement to cross, we saw that children delayed initiation of crossing relative to adults. This resulted in less time to spare when children cleared the path of the approaching car. Given that children should have chosen larger gaps to compensate for their delayed movement, these results indicate that gap decisions and crossing actions are less well matched in children than in adults.

One important question these findings raise is why do children delay initiation of movement relative to adults? One possibility is that children have less precise control over the synchronization of self and object movement. To evaluate this explanation, we created a gap interception task to study synchronization of self and object movement independent of movement initiation and gap selection factors (Chihak et al., 2010). Ten- and 12-year-old children and adults rode an instrumented bicycle through an immersive virtual environment. At each of 12 intersections, participants attempted to pass between two moving red blocks without stopping. Block motions were timed such that participants would arrive early or late in the target gap if they maintained constant speed. This meant it was necessary for participants to speed up or slow down in order to intercept the gap.

As in our road-crossing studies, children had less time to spare than adults when they intercepted the target blocks. Children also exhibited significantly more variability 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 did adults. Children’s approach profiles were also more erratic than those of the adults, with more pronounced corrections in speed as they approached the intersection. In sum, although the patterns of interceptive actions were similar in children and adults, children’s interceptive actions were less finely tuned than those of adults. These findings underscore the difficulties that even 10- and 12-year-old cyclists experience in precisely timing their movement relative to that of fast-moving objects.

We have also examined how children and adults link decisions and actions in more challenging road-crossing situations, such as high-density traffic (Plumert et al., 2011; Stevens et al., in press). Of particular interest was how high-density traffic affected gap choices and movement timing, and how children’s movement timing changed across the course of the session. Based on previous research, we expected children and adults to accept tight gaps when faced with high-density traffic (Guth et al., 2005). While riding in the bicycling simulator, 10- and 12-year-old children and adults crossed 12 intersections with continuous cross-traffic coming from their left-hand side. In the control condition, children and adults encountered randomly ordered gaps ranging from 1.5 to 5 s at all intersections. In the high-density condition, children and adults encountered a set of four intersections with high-density traffic sandwiched between two sets of four intersections with randomly ordered gaps ranging from 1.5 to 5 s.

We found that both children and adults took much smaller gaps when faced with high-density than low-density traffic. Moreover, 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 more closely match their (risky) decisions. However, children were hit on an average of 20% of the high-density intersections, whereas adults were almost never hit. This indicates that although children attempted to bring their actions closer in line with their decisions, they were often unsuccessful at crossing tight gaps in high-density traffic. We also found general changes in movement timing over the course of the session for the 10-year-olds. During the first four intersections, 10-year-olds had relatively little time to spare when they cleared the path of the car. By the last four intersections, they had increased their time to spare by an average of 25% even though they were taking smaller gaps..

What do the results of our work on crossing a single lane of traffic tell us about how children and adults link decisions and actions in dynamic environments? With respect to decisions, we consistently find that 10- and 12-year-olds choose the same size gaps as adults, and that both children and adults choose smaller gaps when the traffic is dense. With respect to actions, we consistently find that 10- and 12-year-olds are less adept than adults at coordinating their movement with that of the traffic. This is particularly true of 10-year-olds, though they do show improvement in coordinating self and object movement over the course of a single experimental session. Both children and adults cut in more closely behind the lead car when they choose tight gaps, but children are often “hit” when they choose tight gaps. Putting these findings together, it appears that children are attempting to adjust their actions to fit their decisions, but they are not fully adjusting their decisions to fit their action capabilities.

Linking Decisions and Actions When Crossing Two Lanes of Opposing Traffic

Our most recent work has examined how 12- and 14-year-olds and adults select and cross gaps when faced with two lanes of opposing traffic (Grechkin et al., 2013). Judging gap affordances when crossing multiple lanes of opposing cross-traffic is a considerably more challenging task than crossing a single lane. The rider must select a pair of gaps composed of a near lane gap and a far lane gap that in combination afford safe crossing. Furthermore, because the rider must be able to move from the near lane into the far lane of traffic while both gaps are open, the spatio-temporal relationship between the gaps in the pair is critical in determining whether a safe crossing is possible. Finally, identifying gap pairs that afford safe crossing is further complicated by the fact that the gaps in traffic approach from opposite directions and cannot be simultaneously observed. Thus, the rider must integrate temporal information across two directions to determine relative times of arrival of the two approaching gaps embedded in two streams of moving traffic.

The temporal offset between the opening of the near and the far gaps provides riders with two qualitatively different opportunities for crossing. In an “aligned” gap pair, the far gap opens before or with the near gap. Conversely, in a “rolling” gap pair the near lane gap opens before the far lane gap. If the temporal offset is sufficiently large, the cyclist can enter the near lane before the far gap opens. For both rolling and aligned gaps, the second lead vehicle to pass the rider’s line of travel acts as a gate to the gap pair. Once it passes the rider, both gaps are open and the rider can move from the near lane to the far lane. In order to maximize the temporal safety margin when crossing two lanes of traffic, riders should therefore key their movements with respect to arrival time of the second lead vehicle in the selected gap pair.

Timing one’s movement is likely more difficult when crossing through a rolling gap pair than through an aligned gap pair. For an aligned gap, the rider can focus attention on the lead vehicle in the near lane – once it has passed both gaps are open and the rider can speed across the entire roadway. However, to optimally cross a rolling gap the rider must time their motion with respect the sequential arrivals of the two lead vehicles – entering the near lane after the lead car in the near lane passes and then passing as close as possible behind the lead vehicle in the far lane when it arrives. The added demand of dividing attention between both lead vehicles may make rolling gap pairs more difficult to cross than aligned pairs, particularly for children.

Twelve- and 14-year-olds and adults crossed 12 intersections in the bicycling simulator with continuous cross traffic coming from opposing directions. In contrast to our earlier work on single lane road crossing, we observed significant developmental differences in gap selection. Although all three age groups preferred rolling over aligned gap pairs, this preference was stronger for adults. Participants of all ages also showed similar preferences for the near lane gap sizes, matching behavior observed in earlier work with single lane road crossing. This was not the case for the far lane gaps. Twelve-year-olds were significantly more willing than adults to select either an aligned or rolling gap pair containing a small far lane gap, but for 14-year-olds, this was only true for aligned gap pairs. When choosing a rolling gap pair to cross, 14-year-olds tended to select larger far lane gaps on average than did 12-year-olds and adults. As a result, while both 12- and 14-year olds delayed their entry into the far lane of traffic compared to adults, 14-year-olds achieved an average time-to-spare in the far lane that was similar to that of adults and significantly larger compared to that of 12-year-olds.

What do the results of this work on crossing multiple lanes of opposing traffic tell us about linking decisions and actions in dynamic environments? In contrast to our work on crossing a single lane of traffic, we find evidence of children adjusting their gap choices to fit their crossing capabilities. Namely, 14-year-olds chose larger far lane gaps than adults did when crossing through the more complex rolling gap pairs, suggesting that they attempted to compensate for their poorer movement synchronization skills by choosing larger gaps. This suggests that 14-year-olds were better able to match their gap choices to their riding abilities than were 12-year-olds.

Conclusions

This research highlights the complex spatio-temporal character of everyday affordances involving moving objects. To cross a stream of traffic, bicycle riders (and drivers and pedestrians) must integrate perceptual information from the dynamic milieu, make judgments that take their action capabilities into account (which vary depending on mode of transport), and synchronize their movements with the movements of multiple other objects. Our work shows that the ability to tightly link decisions and actions under such challenging circumstances undergoes a protracted period of development. Children between the ages of 10 and 14 are clearly less adept than college-age adults at synchronizing their movements with that of the traffic. However, they generally do not fully compensate for their poorer synchronization skills by choosing larger gaps. We only see a hint of this with the 14-year-olds when they are crossing the challenging rolling gap pairs. This mismatch between decisions and actions may be an important risk factor for car-bicycle collisions involving children in late childhood and early adolescence. Yet much remains to be learned about the processes and mechanisms by which children and adolescents learn to tightly link decisions and actions in dynamic environments. We can think of no better way to honor the memory of Herb Pick than to leverage the realism of virtual environment technology to answer questions that have relevance for improving children's lives.

Acknowledgments

Funding

This research was supported by grants awarded to Jodie Plumert, Joseph Kearney, and James Cremer from the National Center for Injury Prevention and Control (R49/CE001167), the National Institute of Child Health and Human Development (R01-HD052875), and the National Science Foundation (CNS-0750677, IIS 00-02535).

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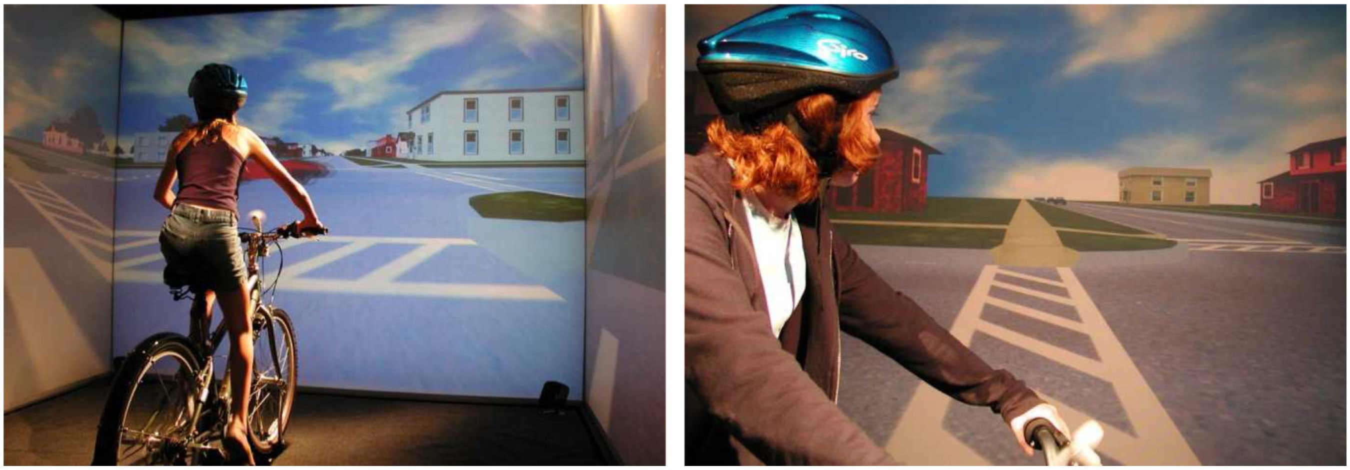

Figures 1.

a (left) and 1b (right). Photographs of the bicycling simulator. Note that the visual angles are correct from the viewpoint of the rider in Figure 1a.