TRAFFIC GENERATION FOR STUDIES OF GAP ACCEPTANCE

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Abstract

Gap acceptance is an essential skill for safe driving and bicycle riding. Road crossing is a complex perceptual-motor task that requires accurate perception of the gap sizes in a dynamic stream of traffic and fine coordination to synchronize the onset of movement with the approaching gap. Understanding how drivers decide that a gap is crossable and how they time their crossing in relation to a moving stream of traffic is critical for the development of training and technology to lower the risk of crashes. This paper presents experimental methods for fine-grained analysis of gap acceptance and intersection crossing behavior using driving simulators. We present a series of techniques for creating scenarios of increasing complexity with traffic in one or two lanes, driving in the same or opposite directions, with traffic streams moving at the same or different spends. By presenting the same temporal gaps in each condition, we facilitate comparison across conditions to better understand how attentional demands and crossing strategies influence gap selection.

Résumé

La perception de l’intervalle de sécurité est un élément essentiel pour une conduite sûre en automobile et en deux-roues. La traversée d’intersection est une tâche perceptivo-motrice complexe qui exige la perception précise des intervalles dans un flux dynamique de trafic et une bonne coordination pour synchroniser le début du mouvement avec le prochain intervalle. Comprendre comment les conducteurs décident qu'un intervalle est franchissable et comment ils gèrent leur traversée par rapport à un flot de trafic se déplaçant est critique pour le développement de la formation et de la technologie destinées à diminuer les risques d'accidents. Cet article présente des méthodes expérimentales pour l'analyse fine d’intervalles de sécurité et le comportement en traversée d’intersection, en utilisant des simulateurs de conduite. Nous présentons une série de méthodes pour créer des scénarii de complexité croissante avec un trafic d’une ou deux voies, allant soit dans la même direction, soit dans des directions opposées, avec des flots de trafic se déplaçant à même vitesse ou des vitesses différentes. En présentant les mêmes intervalles temporels dans chaque condition, nous facilitons la comparaison pour mieux comprendre comment l’attention demandée et les stratégies de traversée influencent le choix des intervalles.

Gap acceptance plays a crucial role in safe driving. Crossing-path crashes account for 25% of all crashes on U.S. roadways and about 45% of crashes at intersections (Ragland & Zabyshny, 2003). Safe road crossing is a complex perceptual-motor task that requires accurate perception of the gap sizes in a dynamic stream of traffic and fine coordination to synchronize the onset of movement with the approaching gap. Understanding how drivers decide that a gap is crossable and how they time their crossing in relation to a moving stream of traffic is critical for the development of training and technology to lower the risk of crashes.

Most of the research in gap acceptance has been conducted by observing the gaps real drivers select in natural traffic. These studies have typically focused on estimating the "critical gap" – the minimal gap size acceptable to a population of drivers (Gattis & Low, 1999; Daganzo, 1981; Mahmassani & Sheffi, 1981). The critical gap is an important factor used by traffic engineers to estimate the throughput capacity of intersections.

Studies of gap acceptance have concentrated on how drivers cross through a single stream of traffic. In day-to-day experience, drivers commonly face the difficult challenge of crossing multiple lanes of traffic coming from opposing directions. Further complicating matters, drivers must attend to pedestrians and bicyclists who may cross their line of travel. Little is known about how drivers cope with the everyday complexity of crossing roads under these circumstances.

One of the challenges in conducting observational studies of gap acceptance is that there is little means to control the distribution of gaps presented to the subjects. Natural variations in traffic cause the gaps available to vary unpredictably from driver to driver. This makes it difficult to examine differences in gap selection between subject populations (e.g. to compare novice and experienced drivers.) In addition, studies have shown that gap order influences the size of the gap a driver will accept. For example, (Kettelson & Vandehey, 1991; Adebisi & Sama, 1989) found that drivers who have long wait times tend accept smaller gaps. The investigators speculate that this may be due to improved judgments with longer time to examine the traffic stream or with increased impatience during long wait times. If the sequence of gaps is uncontrolled, then different subjects may have radically different distributions of traffic making it difficult to compare performance between groups.

Interactive simulation is proving to be a valuable tool for the study of driver behavior. Experiments can be conducted in a driving simulator under carefully controlled conditions without putting subjects in harm's way. Motions can be recorded and replayed for detailed analysis of the relationship between the driver's motion and surrounding traffic and events.

The focus of this paper is on experimental methods for fine grained analysis of gap acceptance and intersection crossing behavior using driving simulators. Over the past ten years, we have developed a real-time simulator, Hank, to serve both as a testbed for scenario research and as a platform for the study of the driving and bicycle riding behavior of children and adults. A central focus of our recent work has been on how bicyclists cross through streams of traffic at intersections. The task of crossing a traffic-filled roadway is much the same for drivers and bicycle riders. We believe that our methods could also be used to study gap acceptance of drivers operating a vehicle.

We first briefly describe our bicycling simulator, and then present a series of techniques we have developed for generating traffic patterns used to probe the complex process of deciding whether or not cross a gap. Finally, we will discuss possible applications of our scenarios to a larger set of gap acceptance studies.

Figures 1a (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.

Gap Acceptance for bicyclists

Vehicle traffic poses a serious threat to the safety of bicycle riders. Motor vehicles are involved in approximately one-third of all bicycle-related brain injuries and in 90% of all fatalities resulting from bicycle crashes (Rivara & Aitken, 1998; Acton et al., 1995). Approximately 500,000 bicycle-related injuries are treated in emergency rooms each year (Baker, Li, Fowler, & Dannenberg 1993). Children between the ages of 5 and 15 represent a particularly vulnerable segment of the population, having the highest rate of injury per million cycling trips (Rivara & Aitken, 1998).

Little is known about why such collisions occur and, in particular, how young bicycle riders make road crossing decisions. In our laboratory, we use an immersive bicycling simulator to investigate some of the underlying behavioral and perceptual issues in bicycling riding behavior. A central focus of our research is gap acceptance behavior for child and adult bicyclists crossing traffic at intersections. A robust finding from our initial research on children's road-crossing behavior is that children choose the same size gaps as adults, but leave less headway when they start to cross. Consequently, child cyclists end up with far less time to spare when they clear the path of the oncoming car (Plumert, Kearney, & Cremer, 2004). This puts child cyclists at greater risk for a collision because they have less time available to recover from an error such as a foot slipping off the pedal.

A second recent finding of this research is that the choices that children and adults make in deciding whether or not to cross a gap are influenced by the pattern of gaps that a subject sees. For example, subjects chose smaller gaps when they first were presented a sequence of very small, uncrossable gaps than when gaps were randomly ordered. Thus, when subjects were forced to wait for a long stream of dense traffic, they were more likely to cross smaller gaps. Interestingly, this lower gap threshold persisted at subsequent intersections that had randomly ordered gaps.

The Bicycling Simulator

Our simulator is pictured in Figures 1a and 1b. Subjects ride an actual bicycle mounted on a stationary trainer. The bicycle is positioned in the middle of three 10 ft wide x 8 ft high screens placed at right angles relative to one another, forming a three-walled room. Three Projection Design F1+ projectors are used to rear-project high resolution, textured graphics onto the screens (1280 x 1024 pixels on each screen), providing participants with 270 degrees

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of nonstereoscopic immersive visual imagery. The viewpoint of the scene is adjusted for each participant's eye height.

The bicycle is instrumented to sense steering angle and pedaling torque applied by the rider. As people ride the bicycle, these sensed values are combined with virtual terrain information and a bicycle dynamics model to compute bicycle speed and direction. The control system employs an 80-foot-pound AC motor to actively drive the bicycle's rear wheel to achieve the computed speed. The bicycle dynamics model accounts for rider and bicycle mass and inertia, virtual terrain slope, ground friction, wind resistance, etc.

The computing platform for the simulation environment is a networked cluster of seven PCs. One PC serves as front-end and experimenter console; one PC is the primary simulation engine; each of three high-end graphics PCs is dedicated to graphics processing and display for one large screen; one PC is dedicated to sound; and one PC provides high-frequency I/O and dynamics for the instrumented bicycle. The underlying software system is a real-time, ground vehicle simulator developed in-house that supports road modeling, vehicle behavior programming, and scenario development (Cremer, Kearney, & Willemsen, 1997; Wang, Kearney, Cremer, & Willemsen, 2005; Willemsen, Kearney, & Wang, 2006).

Gap Generation on a single lane

Our initial studies focused on a relatively simple situation with minimal distraction, where traffic was only present on the near lane of the road to be crossed with vehicles approaching the intersection from the left of the subject. Vehicles traveled at constant speed, so the gaps between vehicles remained constant once cars were created.

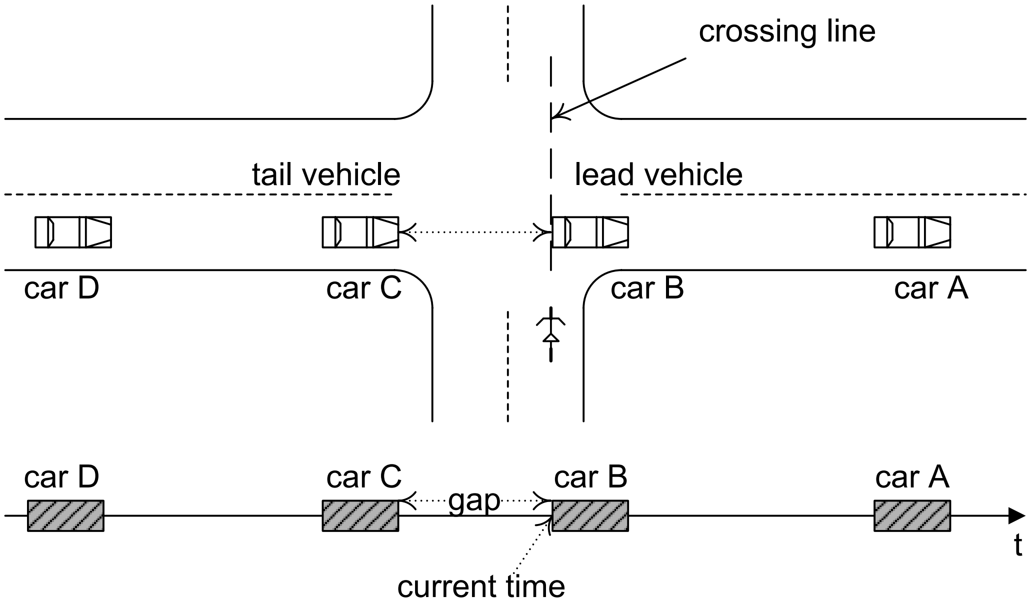


Figure 2. A schematic diagram of the one-lane crossing task. The blocks on the timeline correspond to the temporal intervals during which a vehicle occludes the rider's path. Thus, the open intervals on the timeline represent temporal gaps in the traffic

Our first experiment explored how subjects select gaps presented in random order. We define a gap between two vehicles as the interval of time between the moment the rear of the lead vehicle reaches the crossing line to the moment the front of the tail vehicle reaches the crossing line (Plumert, Kearney, & Cremer, 2004). From the point of view of the bicyclist, a gap represents an opportunity for crossing. During this time period, they must enter and completely traverse the lanes to be crossed. The temporal constraints imposed by crossing are visually depicted in figure 2.

To control gap generation, we created a computational object called a ***source*** that creates new vehicles and injects them into the simulation. Our initial source produced a continuous stream of traffic with gaps organized in logical blocks. Each block contained a random permutation of five different gap sizes: 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5 seconds. This ensured that subjects had a fair chance to see all gaps. The source was placed a sufficient distance from the intersection that the cars did not pop into view when they were created. A sink (an object that destroyed vehicles) was placed on the opposite side of the intersection sufficiently far away that it was not apparent when objects were removed from the simulation.

Our second experiment was designed to test the influence of forced waiting on gap acceptance. For this scenario we created a new *long wait* source object that first produced a stream of randomly ordered uncrossable gaps (1.5 and 2 seconds). When subjects arrived at the intersection, they were to see 8-10 of these uncrossable gaps followed by alternating sets of two same-size crossable gaps and four randomly ordered uncrossable gaps (1.5 and 2 s). The size of the crossable gaps increased in staircase fashion, starting with gaps of 3 seconds and thereafter increasing with each subsequent crossable pair by .5 seconds. The long wait source is a natural extension of our original random gap source with a trigger that switches from the initial stream of uncrossable gaps to the staircase mode based on the subject's approach to the intersection.

Gap Generation For Split Attention Scenarios

Our work to date has always used a highly simplified situation to assess how well children and adults make road-crossing decisions – cars always travel at the same speed, come only from the left-hand side, and stay in the nearest lane. We have relied on this particular road-crossing scenario because we wanted to examine children's road-crossing behavior under the simplest of circumstances. Real-world crossing situations can be considerably more complex requiring more complex perceptual judgments and more difficult coordination of movement.

With recent additions to our library of source objects we are now beginning a new series of experiments to explore the role of anticipation and split attention in gap selection and crossing behavior. In these scenarios we are going to produce the same temporal gaps with traffic in multiple lanes, driving at different speeds with adjacent lanes moving in either the same or different directions.

By introducing a second lane of traffic, we aim to further investigate differences between adults and children in intersection crossing. We expect that children will have more difficulty than will adults with dividing their attention between the two lanes of traffic, particularly when the cars are traveling at different speeds.

The first modification is a simple extension of our original one-lane stream of traffic with random-sized gaps to place traffic in two lanes moving in the same direction (i.e. on a one-way road). The traffic is generated by object called a *twin* source, which produces cars in two different locations in a synchronized manner. The twin source creates vehicles at the same times as in the one-lane case, but randomly varies the lane in which they are created. Thus, the gaps between successive vehicles are preserved. However, the leader and tail of the gap may be in different lanes.

Distributing the traffic in two lanes instead of one lane changes the crossing task in two interesting ways. On the one hand, bicyclists now have to cross two lanes instead of one; thus they are likely to take bigger gaps. On the other hand, the two-lane traffic configuration can sometimes provide an opportunity to get a head start on crossing. Consider a gap, where the lead vehicle is located in the far lane and tail vehicle is located in the near lane. The rider can gain a significant advantage by crossing the near lane before the arrival of the lead vehicle in the far lane. When the lead vehicle passes, the bicyclist need only finish crossing the near lane before the arrival of the tail vehicle and then cross the far lane of traffic before the arrival of the next vehicle in the far lane. By staging the crossing, the rider can reduce the size of the composite gap (the gap between two successive arrivals at the rider's line of travel).

Our previous results showed that adults anticipate the arrival of the leader better than children in one-lane crossing (often initiating their motion before the lead vehicle reaches their line of travel) (Plumert, Kearney, & Cremer, 2004). We expect to see this difference accentuated in two lane crossing.

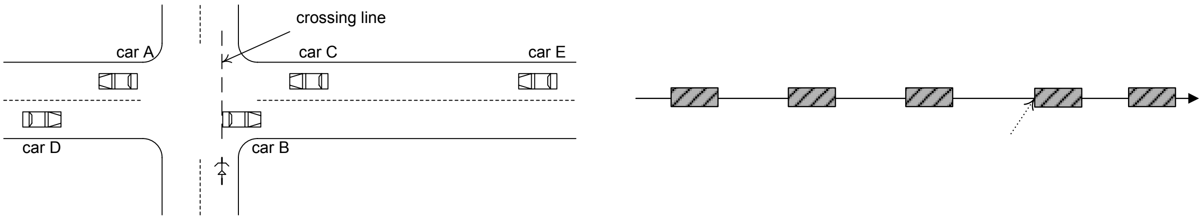
Our second modification uses the twin source to produce random-sized gaps in traffic coming from opposite directions on the road to be crossed. By placing the points of creation at equal distances from the rider's line of travel on opposite sides of the intersection, we can create the same distribution of gaps with traffic approaching from two opposing directions. Since vehicles drive at a constant speed, the time required to arrive at the crossing line will be same for all vehicles. Thus, we provide the same temporal gaps as in the one-lane and two-lane, one-way cases. The temporal gaps will not be the same at different crossing points. However, small deviations in the line of the driver/riders line of travel will have only a minor influence on the size of the temporal gaps.

Finally, we modify the two-lane, one-way random-gap experiments too produce traffic streams moving a different speeds in the two lanes. To preserve the same choice of gap sizes, we place the point of creation at different distances from the crossing line, so that travel time between creation point and crossing line is the same for all vehicles. We can also extend this approach to two-way traffic moving at different speeds in opposite directions. As shown in Figure 3a, the set of temporal gaps are once again preserved.

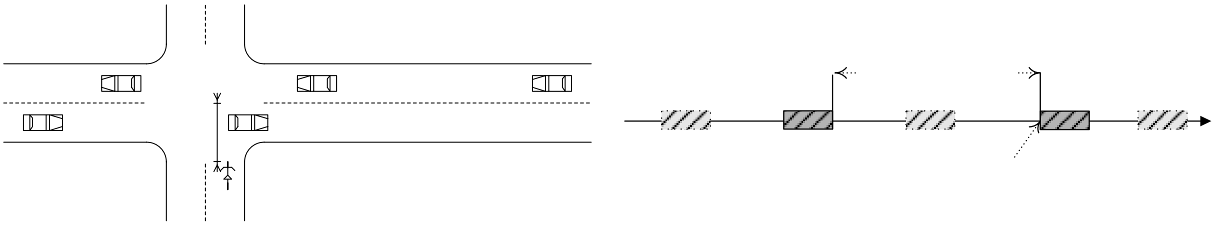
Discussion

Gap acceptance is an essential skill for safe driving and bicycle riding. Studies of gap acceptance behavior can provide insight into how driving/riding populations differ in making this critical judgment, how crossing decisions are influenced by contextual factors (including the properties of the traffic and the configuration of the intersection), and how new technology may aid drivers in safe crossing.

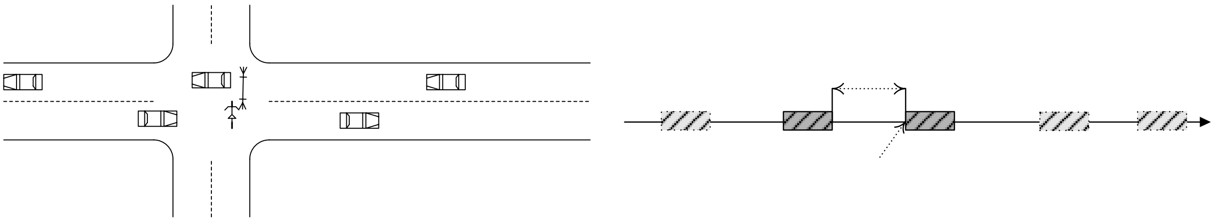
By structuring the traffic, with controlled gap sequences, simulators provide a basis for careful examination of the factors that influence gap selection and give researchers the ability to exam how drivers coordinate their movements in relation to the moving gap through which they cross. The ability to control the presentation of gaps is a significant advantage of simulation over field studies where gaps are uncontrolled and vary widely from driver to driver.



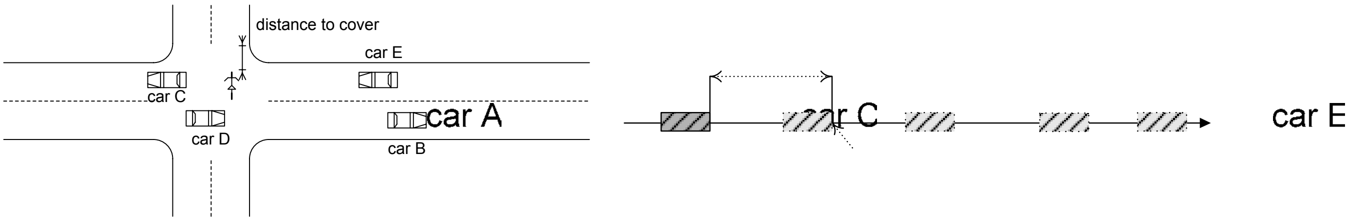
(a) Two-lane crossing task with cars coming from two directions. The times at which the vehicles occlude the rider's line of travel, and hence the temporal gaps, are the same as in Figure 2.



(b) stage 1 – bicyclist moves to the center lane of the intersection



(c) stage 2 – bicyclist clears first lane



(d) stage 3 – bicyclist finishes crossing

Figure 3 (a-d). A schematic diagram of the two-lane crossing task with traffic coming from two directions and staged crossing

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Analysis of gap acceptance data is complicated by acceptance curve bias that results from overrepresentation of cautious drivers in data set (Gattis & Low, 1999). More cautious drivers are more likely to reject small gaps than less cautious drivers (who are likely to jump at the first reasonable chance to cross.) This means that cautious drivers contribute more reject decisions to the data (many of these for gaps that a less cautious driver would have taken if they had the chance.) Estimates of the population-wide critical gap based the acceptance curve (an aggregate plot of the fraction of the gaps of accepted for various size gaps) will be biased in the direction of larger gaps because of the greater numbers of decisions made by the more cautious drivers.

Stair-step presentations avoid this bias by giving a direct estimate of the critical gap. Drivers presumably accept the first gap judged to be crossable. The stair-step method starts with very small gaps and then gradually increases gap size. The progressive pattern assures that if drivers choose the first gap judged to be crossable, then the selected gap will be the minimally acceptable gap. The population-wide critical gap can be estimated by the average size of the accepted gaps. All drivers contribute equally to this estimate.

There are two potential flaws in this approach. First, there is evidence that drivers who experience long waits will accept smaller gaps. Thus, the stair-step method may lead to underestimation of the critical gap if drivers wait a long time before seeing gaps of a crossable size. Second, if drivers are aware of the stair-step structure they may alter their criteria because they know that larger gaps are coming. This could lead to an overestimation of the critical gap. Additional experimentation is needed to determine how these factors influence gap selection.

To date, driving simulation research has principally focused on how drivers respond to critical situations and events that can precipitate crashes (e.g. a sudden stop by the lead vehicle or an unexpected incursion into the roadway by a vehicle waiting on a cross street.) While understanding how drivers respond to dangerous circumstances is important, there is much to learn about the more ordinary, everyday aspects of driving, such as road crossing. As with critical events, a key prerequisite for controlled studies of road crossing is development of scenario control methods to create conditions that can be replicated from trial to trial.

In this paper, we present techniques for generating traffic with varying levels of complexity. By presenting the same temporal gaps in each condition, we facilitate comparison across conditions to better understand how attentional demands and crossing strategies influence gap selection. In the future, we plan to embed critical events in a gap acceptance scenario, for example, by having a pedestrian step into the roadway as soon as a driver initiates a motion to cross through a gap.

References

Acton, C., Tomas, S., Nixon, J., Clark, R. Pitt, W., & Battistutta, D. (1995). Children and bicycles: What is really happening? Studies of fatal and non-fatal bicycle injury. *Injury Prevention*, *1*, 86-91.

Adebisi, O. & Sama, G. N. (1989). Influence of stopped delay on driver gap acceptance behavior, Journal of Transportation Engineering. ASCE, 115(3), 305-315.

Ashworth, R. (1970). The analysis and interpretation of gap acceptance data. Transportation Science, 4(3), 270-280.

Baker, S. P., Li, G., Fowler, C., & Dannenberg, A. L. (1993). *Injuries to bicyclists: A national perspective.* Baltimore, MD: The Johns Hopkins University Injury Prevention Center.

Cremer, J., Kearney, J., & Willemsen, P. (1997). Directable behavior models for virtual driving scenarios. *Transactions of the Society for Computer Simulation, special issue on Multiagent Systems, 14(2),* 87-96.

Daganzo C. F. (1981). Estimation of gap acceptance parameters within and across the population from direct roadside observation. *Transportation Research, Vol 15B., pp 1-15.*

Gattis J. L., Low S. T. (1999). Gap acceptance at atypical stop-controlled intersections. *Journal of Transportation Engineering, Vol. 125, No. 3, pp. 201-207.*

Kettelson, W. K. & Vandehey, M. A. (1991). Delay effects on driver gap acceptance characteristics at two-way stop-controlled intersections, *Transportation Research Record 1320, TRB,* National Research Council, 154-159.

Kyte, M., Kittelson, W. K., Tian, Z., Brilon, W., Troutbeck, R., & Mir, S. (1994). New measurements for saturation headways and critical gaps at stop-controlled intersections, *Proceedings of the Second International Symposium on Highway Capacity*, 1, 345-364.

Mahmassani H., Sheffi Y. (1981). Using gap sequences to estimate gap acceptance functions. *Transportation Research,* Vol. 15 B., pp. 143-148.

Plumert, J. M., Kearney, J. K., & Cremer, J. (2004). Children's perception of gap affordances: Bicycling across traffic-filled intersections in an immersive virtual environment. *Child Development*, 75(4), 1243-1253.

Ragland, D. R. & Zabyshny, A. A. (2003). Intersection decision support project: Taxonomy of crossing-path crashes at intersections using GES 2000 data, U.C. Berkeley Traffic Safety Center, Paper UCB-TSC-RR-2003-08.

Rivara, F. P., & Aitken, M. (1998). Prevention of injuries to children and adolescents. *Advances in Pediatrics*, *45*, 37-72.

Wang, H., Kearney, J.K., Cremer, J., and P. Willemsen, P. (2005). Steering behaviors for autonomous vehicles in virtual environments. *Proceedings of the IEEE Virtual Reality Conference*, Bonn, Germany, pp. 155-162.

Willemsen, P., Kearney, J.K., and Wang, H. (2006). Ribbon networks for modeling navigable paths of autonomous agents in virtual environments, *IEEE Transactions on Visualization and Computer Graphics*, v. 12, n. 3, pp. 331-342.