Discrimination and Estimation of Time-to-Contact for Approaching Traffic Using a Desktop Environment

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Abstract

Each year, thousands of pedestrians are injured or killed in traffic accidents. Identifying pedestrians' perceptual capabilities for street crossing decisions is an important problem. This paper examines this issue by seeking to understand people's time-to-contact judgments for short-range to long-range times-to-contact in a desktop environment. Two experiments were used to test time-to-contact judgments around 4, 7, and 10 seconds. Both experiments showed subjects videos of a car moving down a road toward the viewer. The first experiment observed subjects' ability to discriminate between two different time-to-contact values. The second experiment measured subjects' absolute time-to-contact estimates. We found subjects to be accurate at both discriminating and estimating time-to-contact in a desktop environment. However, performance worsens at longer time ranges, those that pedestrians typically use in street-crossing decisions. Our discrimination thresholds are consistent with other time-to-contact work, and thus illustrate that desktop environments are plausible settings to use for time-to-contact studies.

CR Categories: I.3.m [Computer Graphics]: Miscellaneous—Perception

Keywords: time-to-contact, psychophysics, pedestrian traffic crossing

1 Introduction

Traffic accidents claimed the lives of over 4500 pedestrians in the U.S. in 2003 [National Center for Statistics and Analysis 2003]. The goal of this work is to identify perceptual capacities that affect pedestrians' access to information about traffic and street crossings. Visual cues, such as arrival time of approaching cars and the relative sizes of other objects are potential factors that may influence street-crossing judgments. We would like to establish that people's perceptual capabilities allow them to reason similarly about the above mentioned factors when they are presented in a desktop or immersive virtual environment.

Our focus is on perceived arrival time, or time-to-contact (TTC), and how it provides visual information to pedestrians. Formally, TTC is the time remaining until a moving object reaches an observer or a particular location. The main goal of our experiments is to determine how ability to make TTC judgments varies from short- to long-range TTCs in typical pedestrian-crossing situations. Much TTC research has modeled the moving object as a simple expanding circle or square [Gray and Regan 1999; Todd 1981]. In this paper, we use a graphical model of a car to simulate real-world TTC conditions in street-crossing decisions. Most work in the TTC literature also involves slowly moving objects approaching from several meters away with arrival times less than about 4 seconds [Benguigui et al. 2003; Bootsma and Craig 2002]. But pedestrians must cross in front of rapidly moving vehicles, making crossing decisions when the vehicles are perhaps 70 to 200 feet distant with arrival times of around 4 to 10 seconds. Thus our study observes TTC judgments in this range. In addition, we examine TTC judgments for vehicle speeds from 10 to 30 miles per hour [Pitt et al. 1990]. This range of vehicle speeds corresponds to traffic in settings where pedestrian activity is high.

We also are interested in the accuracy of TTC judgments for desktop virtual environments. In the context of automobile traffic, our task is to determine whether judgments that people make about TTC through a desktop simulation are similar to those found in the literature for other TTC tasks [Schiff and Detwiler 1979; Cavallo and Laurent 1988]. This paper presents the results of two experiments to examine short- and long-range TTC judgments. Both experiments use animated videos of a car model moving along a direct path toward the viewer. Experiment 1 is a discrimination task in which subjects are presented with two car videos with different TTCs and asked to select the car with the shorter arrival time. Experiment 2 is an estimation task in which subjects are shown videos of an approaching automobile and asked to guess the arrival time of the car.

2 Background

TTC research can be divided into two main categories according to the experimental methodology. One category is coincidence anticipation tasks, which involve having subjects estimate when a target will reach a given position [Tresilian 1995]. Two subsets in this category are prediction-motion tasks, where the moving object is occluded from view before it reaches the observer or specified point, and interceptive action tasks, such as catching or hitting balls [Benguigui et al. 2003; Caljouw et al. 2004]. Similar to this work, Plumert et al. [2004] examined how adults and children judged gaps in traffic and decisions to cross streets by riding a stationary bicycle through an immersive simulated environment. The second class of experiments includes relative judgment tasks, in which subjects distinguish between different values of TTC [Tresilian 1995; DeLucia and Novak 1997]. In our study, we examine the correlation between these two approaches through a relative judgment task and a prediction-motion task.

Many TTC studies aim to understand how people estimate TTC. Lee proposed that the means for obtaining the perceptual informa-

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tion necessary to estimate TTC is a quantity named τ [Lee 1976]. It is defined as the inverse of the relative rate of expansion of the retinal image of the moving object. Lee suggested that this cue is what people rely on to make a TTC judgment, although there is debate about its influence [Bootsma and Craig 2002; Smeets et al. 1996; Heuer 1993]. Our study does not focus on which variables underlie TTC judgments but instead on how judgments vary according to the overall TTC range.

Two important trends among TTC studies related to our work have generally been acknowledged. The first is that discrimination thresholds for small TTC differences are usually around 5-10% [Todd 1981; Simpson 1988]. The second trend is that people tend to have a conservative bias when estimating TTC [Schiff and Detwiler 1979; Cavallo and Laurent 1988; Gray and Regan 1999]. This bias means that they tend to underestimate TTC. Our study aims to examine these trends at short and long TTCs.

3 Method

To compare TTC judgments at short- to long- time ranges, we conducted a study with two experiments, a discrimination task and an estimation task. Videos of a car moving down a road directly toward the viewer at different TTCs, velocities, and starting positions were used. We rendered the car on a direct approach as opposed to the view that a person might have upon deciding whether to cross the street. We chose this option because it is the simplest situation and is consistent with approaches taken in other TTC studies, e.g., [Schiff and Detwiler 1979].

3.1 Participants

Eight Vanderbilt University students, five males and three females, completed both tasks in this study. Subjects' ages ranged from 24-29. All had normal or corrected-to-normal vision and were compensated for their participation.

3.2 Materials

The rendered car images were modeled to preserve real-world proportions and viewing conditions. Dimensions of the road followed guidelines in [Iowa Department of Transportation 2005]. We rendered images of the approaching cars at a resolution of 720×480. To light the scene, we used a single directional light in the direction of the camera. We rendered the scenes without shadows and without compression. Shadows can provide important depth cues, but for an outside scene, they would be time-of-day dependent. In the real world, for low to the ground objects like cars, shadows may provide an extra perceptual cue that our studies will not capture.

Two-second videos were generated for TTCs from 2 to 14 seconds at 0.25-second intervals. A given TTC was represented in five separate videos, each with one of five car velocities: 10, 15, 20, 25, and 30 mph. A velocity and a TTC value determined the starting distance of the car in the first video frame. To compare short- to long-range TTCs, we designed our experiments to be centered around three reference TTCs: 4, 7, and 10 seconds. Example images are shown in the color plate. A black screen followed each animation to prevent the viewer from gaining any more visual information after the presentation of the stimulus.

To accurately represent the perspective of an observer, the observer's viewing angle was maintained in the rendered images. Therefore, for example, when the 6.5-foot-wide car was 440 feet away (a TTC of 10s at a velocity of 30 mph), the viewing angle would be approximately 0.84°. We calibrated the sizes by assuming a viewing distance of two feet from the screen, and enforced it by requiring viewers to watch the videos through an enclosure. The enclosure, a black box, was attached to the monitor such that it framed the videos. The viewing box also served to minimize distractions from the surrounding room.

3.3 Procedure

Subjects were given a set of written instructions for each experiment. The order of experiments was counterbalanced across subjects. Both experiments were performed binocularly.

3.3.1 Procedures for Experiment 1: Discrimination

Subjects were presented with a pair of two-second videos and asked to determine which car would reach them first. The videos were presented consecutively with a 2.5s black screen between them. Each pair of videos had a video with one of the three TTC reference values: 4s, 7s, or 10s, and another video with a TTC that was greater or less by an amount that varied across trials according to an adaptive threshold rule. The order of the pair of videos within each trial was random. Separate threshold estimates were obtained for the reference values of 4s, 7s, and 10s, but these threshold procedures were interleaved, so that from a subject's perspective, a wide range of TTCs was presented. Each threshold procedure was a staircase in which the difference between TTCs on a trial was decreased (made more difficult) after two consecutive correct trial outcomes, and increased (made less difficult) after an incorrect trial [Wetherill and Levitt 1965]. Increases and decreases in TTC differences were performed in 0.25s increments. The experiment ended when the subjects reached 10 reversals or gave seven correct answers in a row for the lowest TTC difference, 0.25s. A reversal consisted of an incorrect answer after a prior sequence of two consecutive correct answers or two consecutive correct answers after a sequence of incorrect and single correct answers. No subject in our experiment discriminated successfully seven times in a row at the 0.25s difference. To discourage subjects from using only image size as a cue, one of the five velocities was randomly selected for each video.

The videos were designed to match the ranges of vehicle speed and distance over which pedestrians typically have to make street crossing decisions. Over these ranges, the image size of a vehicle is not a reliable cue for approach time. Given that both videos were selected randomly across a range of starting distances, and that image size is directly proportional to starting distance, image size was strongly decoupled from the TTC.

3.3.2 Procedures for Experiment 2: Estimation

In Experiment 2, the estimation task, participants were shown videos of the same car with TTC references of 4s, 7s, or 10s, followed by a blank screen. For each two-second video, subjects were asked to press a key when they thought the car would reach them. 30 trials, 10 for each TTC reference, were presented to each subject in a random order.

Subject	TTC Ref. = 4s	TTC Ref. = 7s	TTC Ref. = 10s
1	0.38	0.38	2.25
2	0.44	1.63	2.63
3	0.50	0.81	1.44
4	0.38	2.00	1.56
5	0.50	2.00	2.13
6	0.63	0.75	1.63
6	0.69	0.44	1.69
8	0.69	1.38	1.25
Means (Std. Error)	0.52 (0.05)	1.17 (0.24)	1.82 (0.16)

Table 1: Discrimation threshold for each subject by TTC reference for the discrimination task (Experiment 1). These values were computed by subject as the average of the last four reversals. Also shown are the population mean and standard error of the mean.

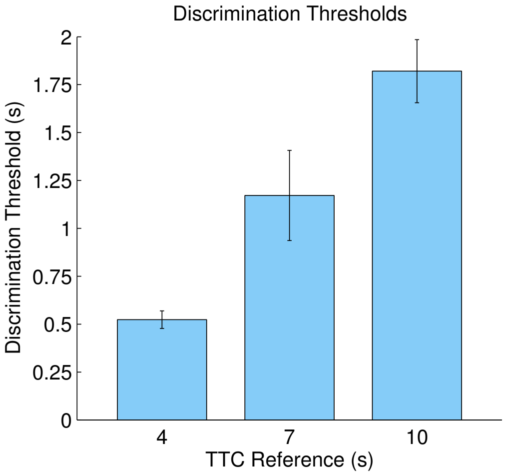

Figure 1: The mean values for the discrimination task (Experiment 1). The means were determined by averaging the final four reversals for TTC reference times of 4s, 7s, and 10s. Error bars show standard errors of the mean.

4 Results

Table 1 and Figure 1 show the discrimination thresholds for each participant that were computed as the average of the TTC differences at the last four reversals. A trend analysis of variance was performed with TTC Reference (4, 7, 10) as the repeated-measures factor and Task Order (Experiment 1 first and then Experiment 2 or vice versa) as the between-groups factor. There was a significant linear trend for TTC References, $F(1,6) = 50.717$, $p < .001$. Neither Task Order nor the interaction effect was significant.

Discrimination thresholds were also converted from seconds to a proportion of the reference TTC to assess whether discrimination ability is a constant proportion of the reference value of TTC. For example, a threshold of 0.8s in the 4s condition would be converted to $(0.8)/4 = 0.2$. Mean relative thresholds were 0.13%, 0.17%, and 0.18% of the 4, 7, and 10 reference values, respectively, and are shown in Figure 2. These relative thresholds were analyzed with the same design including TTC Reference and Task Order. Again, only the linear trend for TTC Reference was significant, $F(1,6) = 6.005$, $p < .05$. Although the significant linear trend suggests that discrimination worsens even in relative terms as the overall TTC goes up, the trend is not as robust statistically as for the thresholds measured in absolute number of seconds.

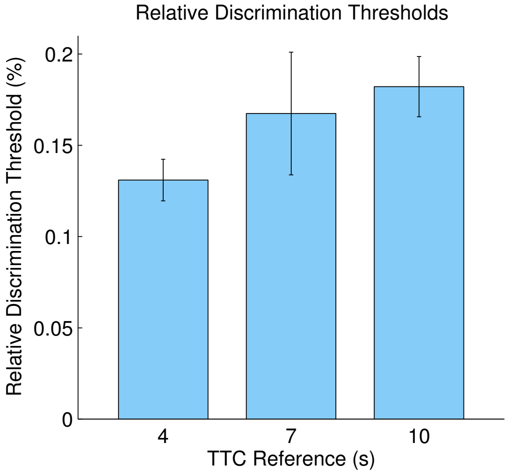

Figure 2: The mean relative threshold for the discrimination task (Experiment 1) as a function of the TTC reference value. Error bars show standard errors of the mean.

Subject	Mean (Std. Error)			Slope
	TTC Ref. = 4s	TTC Ref. = 7s	TTC Ref. = 10s	
1	4.70 (0.32)	9.69 (0.62)	17.79 (1.38)	2.18
2	4.04 (0.16)	7.90 (0.32)	11.45 (0.85)	1.23
3	3.41 (0.14)	4.98 (0.21)	6.77 (0.29)	0.56
4	3.56 (0.34)	5.98 (0.35)	8.15 (0.32)	0.76
5	5.75 (0.43)	9.41 (0.61)	16.55 (1.62)	1.80
6	3.86 (0.24)	6.58 (0.27)	8.40 (0.31)	0.76
7	4.46 (0.48)	8.44 (0.77)	12.12 (0.84)	1.28
8	4.36 (0.48)	7.29 (0.68)	11.02 (1.28)	1.11
Means	4.26	7.53	11.53	1.21

Table 2: For each subject their mean estimated TTC for each reference value with their standard error over 10 trials shown in parentheses. Additionally, for each subject the slope of a linear regression of their data is shown in the final column. The total mean estimated value and average slope are shown in the bottom row.

For the estimation task, the means for each subject for each TTC reference value, along with the standard errors and the slope of the regression line fitted through their means is shown in Table 2. On average, there was a consistent bias towards overestimating the TTC. This result is somewhat surprising, since one might guess that subjects would be biased to not waiting very long and underestimating the TTC. In terms of constant and variable errors, the variable error was the largest component of error for seven subjects. We analyzed variable errors for systematic differences between errors across TTC reference values but found that it was not a significant component of the variable error. Thus, subjects were able to systematically scale their responses according to the reference values, as is evident by the slopes of the regression lines.

Overall, subjects were accurate at estimating TTC. Absolute error was greater for larger reference values, which indicates that subjects were less accurate at larger ranges of TTCs. To examine accuracy relative to the TTC reference value, the mean errors were converted to a proportion of the reference values, similar to the method used for the discrimination thresholds. These errors were 6.7%, 7.6%, 15% for 4s, 7s, and 10s respectively, and differences between them were not statistically significant. No direct correlation was found between participants' accuracy for the discrimination task with that for the estimation task.

5 Discussion

For street crossings in the real world not mediated by a crossing signal, people generally estimate perceived velocities and distances of vehicles, and then choose whether to cross the street based on those observations. They may use a number of cues for this decision, both auditory and visual, but they are estimating, probably conservatively, the time-to-contact (TTC) of the oncoming vehicle. The goal of this paper was to examine time-to-contact (TTC) for approaching vehicles presented through a desktop display. Two experiments were conducted, one a discrimination task and another an estimation task.

In both experiments, people seem to be using strategies similar to those that pedestrians might use to make street-crossing decisions. In post-experiment interviews, subjects reported being aware that both the speed and the apparent size of the car varied, and that they could not rely on only one cue to make their choice. Some subjects remarked that they attempted to count the number of white lane-dividing marks on the road, although they could not elaborate on how this helped them. This strategy is not one that we imagine pedestrians typically employ. Nonetheless, our results generally indicate that similar decision-making processes reported in the literature [Ashmead et al. 2005] for pedestrian crossing are occurring in our laboratory setting using a desktop environment.

For the discrimination task, people were quite sensitive to the TTC and showed thresholds consistent with thresholds determined by other research studies. Additionally, people's level of performance declines absolutely and relatively with longer TTCs. Therefore, pedestrians who have difficulty crossing intersections may need to be more conservative in their judgments. Plumert et al. [2004] find this true especially for children on bicycles, who tend to experience greater difficulty in coordinating their actions with cars and therefore, have less time to spare between themselves and the approaching vehicles.

For the estimation task, people were within 10% (overall) in their judgments. However in our results, people did not consistently underestimate, a finding contrary to the trend reported in other TTC work [Schiff and Detwiler 1979; Cavallo and Laurent 1988; Gray and Regan 1999]. This result is somewhat counterintuitive, since one might guess that subjects would be biased towards not waiting very long after the end of the 2-second video, thus underestimating TTC. However, our result is consistent with studies examining real-world pedestrian situations at traffic roundabouts, which have found that pedestrians with normal vision leave small margins of safety of only a second or two when crossing the street [Guth et al. 2005]. These small gap affordances may reflect a trend to overestimate TTC.

In future work, we intend to broaden our studies to include more typical pedestrian viewpoints, different models of vehicles, wider velocity ranges, and move the experiment into a more immersive viewing system.

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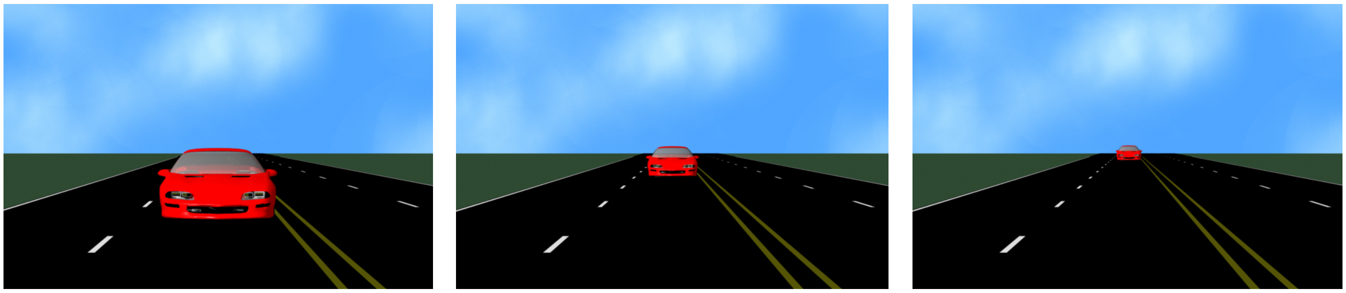
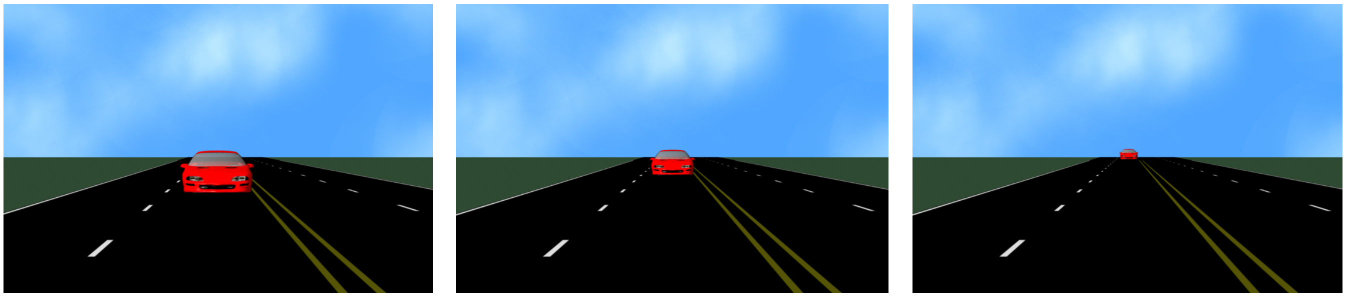


(a) 4s at 10mph. (b) 7s at 10mph. (c) 10s at 10mph.



(d) 4s at 30mph. (e) 7s at 30mph. (f) 10s at 30mph.

Color Plate 1: Examples of the first image in a 2-second video for the lowest (10mph) and highest (30mph) velocities for each of the three reference values of TTC: 4, 7, and 10 seconds.