# Judgment in Crossing a Road between Objects Coming in the Opposite Lane 

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#### Abstract

When cars are oncoming in the opposite lane of a road, a driver is able to judge whether his/her car can cross the road at an intersection without a collision with the oncoming cars. We developed a model for the human judgment used to cross a road between oncoming objects. In the model, in order to make the judgment to cross the road, the human visual system compares the time interval it takes for an oncoming object to pass the observer with the time interval it takes for the observer to cross the road. We conducted a psychophysical experiment to test the model prediction. The result showed that human performance is in good agreement with the theoretical consequence provided by the model, suggesting that the human visual system uses not only the visually timed information of the approaching object but also the timed information of self-action for the judgment about crossing the road. (C) 2008 The Optical Society of Japan


Key words: motion in depth, time to contact, visually timed action

It is well known that we estimate the time-to-contact (TTC) with an approaching object while the object is approaching a particular location. ${ }^{1)}$ In such a situation, much research has considered only TTC information about the approaching object. ${ }^{1-7)}$ However, in a situation where a driver must judge whether his/her car can cross ahead of that oncoming object at an intersection, more complex judgment is needed. In that case, the driver must estimate the time interval when the oncoming car will arrive at the intersection. At the same time, the driver also must estimate the time interval that it will take for his car to cross the road at the intersection. The driver seems to compare these two estimates, in order to decide whether his car can cross the road without colliding with the oncoming car. However, it is not clear how the two estimates are used. In the present study, we developed a model to describe how human observers use the two estimates of TTC of an approaching object and time-to-cross to cross the road. We conducted a psychophysical experiment to test whether the judgment of human observers on crossing the road were the same as the model prediction.

In the situation depicted in Fig. 1, the observer is located at a distance of 0.5 m from the center line of the road in the left lane, and two rigid spherical objects are located far from the observer in the right lane. This geometric situation simulates the Japanese road system. The two objects are approaching the observer at a constant velocity $V$ in the right lane, with a constant distance $D$ between them. Now, consider that the observer judges whether he is able to cross the right lane between the two oncoming objects. Suppose the visual system estimates the following things. First, it estimates the time interval it takes for the second oncoming object to pass him after the first object has passed. We define this time interval as $T_{\mathrm{p}}$. Second, the visual system estimates

[^0]

Fig. 1. Situation in which rigid spherical objects pass the observer in the opposite lane of a road. This geometric situation simulates the Japanese road system. The rigid spherical objects are moving along a straight path at a constant velocity $V$. The distance between them is $D$. The width of the lane is $W$.
the time interval it will take for him to cross the right lane of the road. We define this time interval as $T_{\mathrm{c}}$. Finally, the visual system can, in principle, compare $T_{\mathrm{p}}$ to $T_{\mathrm{c}}$. If $T_{\mathrm{p}}$ is less than $T_{\mathrm{c}}$, the observer will collide with the second oncoming object while he is crossing the road. In this case, the visual system judges that the observer cannot cross the road. If $T_{\mathrm{p}}$ is more than $T_{\mathrm{c}}$, the observer does not collide with the second oncoming object in crossing the road. In this case, the visual system judges that the observer can cross the road safely. If $T_{\mathrm{p}}$ is equal to $T_{\mathrm{c}}$, the estimate of the visual system is on the threshold for going across the road.

In a situation where $T_{\mathrm{p}}$ is equal to $T_{\mathrm{c}}$, consider the relationship between the distance between the two oncoming objects $(D)$ and the width of the lane of the road $(W)$ (see Fig. 1). Here we assume that the acceleration of the observer is constant while he is crossing the road. The velocity of the
moving observer [ $V_{\mathrm{o}}(t)$ ] is given by

$$
\begin{equation*}
V_{\mathrm{o}}(t)=a t \tag{1}
\end{equation*}
$$

where $a$ is his acceleration. When he moves from the center line of the road to the right line of the road, the width of the lane $(W)$ is given by

$$
\begin{equation*}
W=\int_{0}^{T_{\mathrm{c}}} V_{\mathrm{o}}(t) d t=\int_{0}^{T_{\mathrm{c}}} a t d t=\frac{a}{2} T_{\mathrm{c}}^{2} \tag{2}
\end{equation*}
$$

Now, considering that $T_{\mathrm{p}}$ is equal to $T_{\mathrm{c}}$, the width of the lane $(W)$ is given by

$$
\begin{align*}
& W=\frac{a}{2} T_{\mathrm{c}}^{2}=\frac{a}{2} T_{\mathrm{p}}^{2}=\frac{a}{2}\left(\frac{D}{V}\right)^{2} \\
& \Leftrightarrow D=k \sqrt{W} \tag{3}
\end{align*}
$$

where $k\left(=\sqrt{2 V^{2} / a}\right)$ is a constant value. Also, using eqs. (1)-(3), the constant parameter of $k$ is represented by

$$
\begin{equation*}
k=\frac{2 V \sqrt{W}}{\left.V_{\mathrm{o}}(t)\right|_{t=T_{\mathrm{c}}}} \tag{4}
\end{equation*}
$$

Remember that, when $T_{\mathrm{p}}$ is equal to $T_{\mathrm{c}}$, the estimate of the visual system is on the threshold for crossing the road. In eq. (3), therefore, the distance $D$ corresponds to the distance threshold required for crossing the road. Equation (3) predicts that the distance threshold depends on the width of the lane. Thus, if the visual system compares $T_{\mathrm{p}}$ with $T_{\mathrm{c}}$ to decide whether the observer is able to cross the opposite lane between the two oncoming objects, the distance thresholds for crossing that lane should be consistent with the model prediction formulated by eq. (3).

We measured how the judgments of crossing the road between the two oncoming objects were affected by the lane width. Observers sat in a totally dark room and viewed visual stimuli binocularly through polarizing glasses. The observer's head was fixed with a combination of a chin rest and a forehead rest. The visual stimuli were presented by two projectors, which were superimposed to create a threedimensional object in the frontal plane of the observer. The screen subtended 95 deg in width and 79 deg in height when viewed from 72 cm away. The display was controlled by a computer (Apple PowerMac G3). Visual stimuli were created by simulating rigid spherical objects moving on the ground at a constant velocity of $60 \mathrm{~km} / \mathrm{h}$ along a straight path on the opposite lane of a road. A sensation of approaching motion in depth was created by changing the size of the simulated object and by changing its binocular disparity. ${ }^{8)}$ The simulated spherical objects were rendered using anti-aliasing and geometric perspective projection from the observer's eyes. Figure 2 represents the perspective view of the simulated situation. The spherical objects were white disks $\left(50 \mathrm{~cd} / \mathrm{m}^{2}\right)$ on a black background as shown in Fig. 2. The edges of the road were shown by white lines $\left(50 \mathrm{~cd} / \mathrm{m}^{2}\right)$. We manipulated the lane width of the road and the distance between the two spherical objects. The simulated lane width from the center line of the road was varied over values of $2.5,3.5$, and 4.5 m , and the simulated distance between the two spherical objects was varied from 7.0 to 25.0 m . The simulated object diameter was 1.8 m .


Fig. 2. Visual stimuli. Visual stimuli were created by simulating rigid spherical objects moving on the ground at a constant velocity along a straight path in the opposite lane of a road. The spherical objects and the road edges were rendered using anti-aliasing and geometric perspective projections from the eyes.

At the beginning of each experimental trial, the distant spherical object was located 50 m from the observer in the simulated situation. The near spherical object was located in front of the distant object, and the simulated distance between them was randomly chosen. The motion trajectories of the simulated spheres initiated when observers pressed a button. The two spherical objects were presented on the screen until they moved off the screen along the opposite lane of the road. After the two objects disappeared from the display, the observers judged whether they could have gone across the road between the two objects. An experimental run consisted of 90 trials $(3 \times 10 \times 3$, lane widths $\times$ distances $\times$ repetitions). Each observer performed four experimental runs. Three observers participated in the experiment, each having normal or corrected to normal visual acuity. One of the observers had experience in driving a car in both Japan and North America. The other two had experience in driving a car only in Japan.

Figure 3 shows the percentages of the "go" reports as a function of distance between the two spherical objects for observer HH. The circle, square, and triangle symbols represent the lane widths of $2.5,3.5$, and 4.5 m , respectively. The fitting curves were produced by probit analysis. Using the fitting curve, we extracted the distance at which the percentage of the "go" report was equal to $50 \%$. This was defined as the distance threshold for crossing the opposite lane of the road. Figure 4 shows the mean distance thresholds for the three observers as a function of lane width. The solid symbols represent the experimental data, and the dashed line represents the distance thresholds predicted by eq. (3). In this case, the constant parameter of $k$ included in eq. (3) was set to 8.02 . In order to estimate the constant parameter of $k$, we assumed that the velocity of the observers [ $V_{\mathrm{o}}(t)$ ] was $28 \mathrm{~km} / \mathrm{h}$ at the time of $T_{\mathrm{c}}$ under the situation that the width of the lane $(W)$ was 3.5 m and the approaching objects moved at a constant velocity $(V)$ of $60 \mathrm{~km} / \mathrm{h}$. The constant parameter of $k$ was provided by substituting these values for eq. (4). Equation (4) indicates that the constant parameter of $k$ depends on the velocity of the observer at the


Fig. 3. Percentage of reporting to be able to cross the road as a function of distance between two objects for subject HH. The circle, square, and triangle symbols represent the lane widths of 2.5 , 3.5 , and 4.5 m , respectively. The fitting curves were produced by probit analysis.


Fig. 4. Distance threshold as a function of road width. The solid symbol represents the experimental data from the three subjects. The error bars represent S.E. The dashed curve represents the theoretical curve [see eq. (2) in the text]. In this case, the constant parameter of $k$ is set to 8.02 .
time the observer crossed the road. In Fig. 4, the distance threshold increased with the lane width, and was in good agreement with the prediction of eq. (3). Equation (3) is provided when $T_{\mathrm{p}}$ is equal to $T_{\mathrm{c}}$. The human visual system usually estimates the timed information such as TTC under the situation used in the present study. ${ }^{4-6)}$ Considering these things, the result shown in Fig. 4 suggests that the human
visual system may compare $T_{\mathrm{p}}$ with $T_{\mathrm{c}}$, in order to judge whether the observer is able to cross the opposite lane of the road between the two oncoming objects.

In the present study, however, the observers always made judgments of a right turn between the oncoming objects. It is not clear whether the present results are applicable to the case of a left turn at intersections, such as the Western traffic system. In addition, the observers had experience only with the Japanese traffic system except for one indivisual. Therefore, even though they made judgments of a right turn, it is not clear whether these results are applicable to a case where the observers have experience only in the Western traffic system, but not the Japanese traffic system. In future investigations, it would be informative to examine these things.

The present study proposed a model for judgment used to cross a road between oncoming objects. The model predicted that the distance threshold for crossing the road between two objects increased with the width of the lane if the visual system compared the time interval for an approaching object to pass the observer with the time interval for the observer to cross the opposite lane. We confirmed that the result of human observers is consistent with the theoretical consequence represented by eq. (3). Much of the research has considered only TTC information about an approaching object. ${ }^{1-7)}$ However, the present study suggests that, for the judgment to cross a road at an intersection, the human visual system may make an appropriate judgment by using not only TTC information about an approaching object but also the timed information of self-action based on visual information about the width of the road.

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