SPORTATION

UNIVERSITY OF MINNESOTA

THE LEFT TURN

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ABSTRACT

Two experiments are reported which examined drivers' responses in turning left across a line of traffic as presented in a closed-loop, interactive, fixed-base driving simulator. Drivers were located near an intersection and instructed to turn left across a stream of on-coming traffic when they felt that it was safe for them to do so. The on-coming stream of traffic was varied in terms of the physical parameters of approach velocity, inter-vehicle time interval, and vehicle type. Specifically, seven velocities (10-70 mph) were crossed with seven gap sizes (3-9 sec) to yield forty-nine within-subject conditions for each of four, between-subject, vehicle types; motorcycle, compact car, large car, and delivery truck. There were ten subjects per vehicle type, giving a total of forty participants in the first experiment. Results indicated differential acceptance of gap and velocity combinations depending upon the type of approaching vehicle. Collisions tended to occur along the boundaries where driver's decisions to reject or accept turns were ambivalent. They also occurred with greater frequency at higher velocity approach rates. The second experiment replicated the procedure of the first experiment except that the subjects were older drivers, uniformly over the age of 55. Results indicated a greater degree of turn conservatism for this later group. Overall, turn decisions were not dependent upon a single physical parameter such as vehicle velocity or inter-vehicle distance, although gap-size generated an arguable influence. Rather, left turn decisions appeared to result from the complex interplay of rate-of-change perceptual variables such as "time-to-arrival" and the perceived characteristics of the vehicles themselves. Implications of the results are discussed with respect to the perception of vehicles and turn safety at roadway intersections.

INTRODUCTION

It has been estimated that by the year 2025 there will be two billion vehicles on the roads of the world (Keyfitz, 1989). Comparable accident rates would mean one fatality per minute and one lifetime disabling injury will occur each second (Michon, 1990). What needs to be known is how to design and construct the highways and vehicles of the future so that these ominous predictions do not become reality.

Perhaps no frequent driving maneuver is more hazardous than the left turn. While the cost for detection failure during right turns is relatively benign, detection failures of on-coming vehicles in a left-turn can result in particularly severe collisions. As well as its dominance as an accident configuration, the left-turn renders a number of clues that suggest it is amenable to some reduction. Existing statistics based upon the number of vehicle miles driven indicate that the left-turn accident configuration is one in which there are over-representations of drivers in the young 16-24 age range and older drivers aged 65+ (Transportation Research Board, 1988). Motorcycles are more likely to be involved in a collision with a vehicle turning left across their path which results in motorcyclist fatality (National Safety Council. 1987).

Vehicle conspicuity may or may not contribute directly tot he occurrence of an accident. (See conspicuity paper)

Older drivers are over represented in the left turn accident configuration (Yes, need more support refs)

Perception of motion in depth is sometimes difficult for people to perceive. (compared with what perceptions in other configurations of traffic?)

Population statistics of left turn fatalities and injuries serve to provide a mandate for understanding of the problem. Unfortunately, aside from identifying particular accident configurations, geographic locale and age-group involvement, these statistics do little to explain the precursors of these accidents "waiting to happen." Accident reconstruction provides another level of description for analyzing the physical remnants of drivers responding to, or failing to respond to, one anothers adaptive driving behaviors. Questions aimed at the perceptual informational basis for choosing to turn left appear to hold superior promise for researchers attempting to understand driver behavior at intersections (see Scialfa, et al., 1991). Before describing what a person might use as the informational basis for a decision to turn left a thorough description of the left turn is necessary so that we may lay base both the complexity of the scenario and the reducibility of the left turn.

THE LEFT-TURN

Understanding the complexities of the left-turn presents a number of intrinsic challenges. It is unsurprising that the left-turn proves a hazardous configuration as, the turning driver has minimal information available upon which to base their decision. Essentially, on-coming vehicles must be distinguished by cues from perceived motion-in-depth, where the expansion rate and characteristics of the frontal surface area represent the almost sole dynamic sources of information upon which to base the turn decision. Hills (1980) illustrates the problems of on-coming vehicles by illustrating that a small car at two hundred metres distant may only increase one degree of visual arc for every ten meters closer to the observer it travels. (Hmm, this is actually a nonlinear or geometrical relationship and is not served well by this example.)

[What is the informational basis of the left turn?] (subheading)

Three major categories of information have been studied as potential failures of the perceptual system to detect the correct information for deciding to turn left. These categories are the physical characteristics of on-coming vehicles, the vehicular velocity estimation abilities of drivers and rate-of-change information specified by vehicles in motion. In applying these general categories to left turn scenarios, a closer examination reveals that the drivers must perceive and integrate multiple sources of information prior to a decision being made. In a recent experiment, results indicated consistent increases in processing loads for turn maneuvers compared with straight driving (Hancock, Wulf, Thom, and Fassnacht, 1990), results which imply an increased workload associated with driving decisions at intersections. With respect to on-coming vehicles, these must be distinguished from competing sources of information based solely on their expansion rate, physical characteristics of the vehicle such as color and shape and perhaps textural cues between the driver and the approaching car which indicate distance information. Although vehicles themselves specify information, the task of the left turning driver is one of coincident timing, where turn initiation and completion must be synchronized with acceptably safe gaps in on-coming traffic (Gibbs, 1968). Acceptability of the turn is predicated on the perceptions of the individual drivers of traffic in terms of multiple vehicle physical characteristics and rates-of-arrival. Further, vehicles can vary in terms of their approach velocity, the gap difference between themselves and the vehicle they follow, as well as their respective configuration in terms of size, shape, and color (Hills, 1980). If drivers use these physical variables as the basis of deciding to turn, we would expect to see adaptations in turn strategy consistent with the manipulation of physical parameters. If, however, drivers base decisions on other forms of information (e.g., rate of vehicle frontal surface area expansion) available in the display of on-coming vehicles, the pattern of data would not be isomorphic with physical parameter manipulation. Principally, the task of the turning driver is one of coincident timing, where turn initiation and completion must be synchronized with acceptable gaps in on-coming traffic (Gibbs, 1968). Acceptability is predicated on the perceptions of individual drivers (Grubb, 1986; Hills, 1980) of this traffic in terms of presented physical characteristics. Objectively, vehicles can vary in terms of their approach velocity, the gap difference between themselves and the vehicle they follow, and their configuration in terms of size, shape, and color. If drivers key on these physical variables, we would expect to see bifurcations in turn strategy consistent with such physical parameters. If, however, drivers base decisions on other forms of information (e.g., rate of vehicle frontal surface area expansion, time-to-passage) available in the display of on-coming vehicles, the pattern of data would not be consistent with artificial parameters.

The size and configuration of the motorcycle, as a vulnerable on-coming vehicle, provides a likely hypothesis with respect to physical characteristics which may influence the decision to turn left, although many additional factors obviously operate in this complex milieu (Gibbs, 1969; Hills, 1980). In a recent experiment, we have shown consistent increases in processing loads for turns compared with straight driving. However, while the penalty for detection failure during right turns is relatively benign, detection failures of on-coming vehicles in a left-turn can result in particularly hazardous collisions (Hancock, Wulf, Thom, & Fassnacht, 1990).

[What are our primary research questions?]

For any one subject, the type of on-coming vehicle remained constant, but each trial varied on-coming vehicle velocity from 10-70 mph (16-112 kph) and gap size from 3-9 seconds. This gave forty-nine conditions for any one participant. The type of approaching vehicle could be a motorcycle, a small car (Chevrolet Chevette), a large car (Lincoln Continental), or a delivery truck (AMC UPS Van). This factor was a between subject manipulation. There were six subjects for each vehicle type. Analysis of the data were conducted in terms of the number of times the driver successfully turned left versus the opportunities for turning left, and the number of collisions and near collisions which occurred during turns. This proposition was tested in the University of Minnesota high-fidelity fixed-based automobile simulator. The purpose of this experimental work then was to test the influence of such physical parameters as gap size between on-coming vehicles and different velocities on drivers decisions to turn left across traffic.

What information do drivers use to decide to turn left (i.e. distance vs. time)?

Does the size of the on-coming vehicle influence a persons decision to turn left?

Does age influence the conservatism or liberalism of turning strategies?

What are the differences between older and younger drivers when turning left?

What do accidents tell us about the informational basis for deciding to turn left?

EXPERIMENT 1

METHOD

Information Presentation

Each participant was seated in a fixed-base driving simulator (1990 Honda Accord) and viewed a projection screen located 8.4 ft. (2.54 m) in front of the their eyes. The simulation hardware was composed of a 80386, 33MHz CPU, with the XTAR-Falcon 2000 graphics accelerator system connected to an Electrohome ECP-3000 projector which projected scenes to a 10' diagonal screen. The analog to digital inputs were from potentiometers attached to the steering, brake and accelerator. The driver could manipulate accelerator, brake, and steering wheel which actions dictated changes in the computer-generated display. At a software level, the implementation of the graphics worlds presented to the driver is divisible into two parts. The first part uses AutoCAD to specify and integrate the objects and their locations in the driving world. Thus, all road markings and signage were developed according to the specifications of the U.S. Department of Transportation Federal Highway Administration Manual on Uniform Traffic Control Devices (Department of Transportation, 1988) in AutoCAD. The second software part controlled the drivers movement through the world. Driver inputs to the accelerator, brake, and steering wheel changed a traffic scene accordingly. Figure 1 summarizes the composition of the simulation hardware and software.

Insert Figure 1 about here

Participants

There were forty participants in the experiment. Their mean age was 24.2 yrs with a range from 19 to 44 yrs. Generally driving experience paralleled age, with the average weekly miles travelled at 135, with a range from 4 to 580 miles per week. There were sixteen males and twenty-four females randomly assigned to conditions, where the eventual distribution had an approximately even distribution between the sexes for each vehicle type.

Procedure

At the start of each trial, the participant was positioned 30 ft. (9.14 m) from an intersection. The intersection itself was unregulated, that is, it contained no traffic control signs or devices. Each roadway at the intersection was two lanes wide and separated by a double yellow line. The cross road contained no conflicting traffic. Approaching them through the intersection was a line of vehicles across which the driver could choose to turn. Participants were instructed to make a left turn when they felt that it was safe to do so. The verbal protocol to subjects explicitly emphasized that they drive safely, avoiding accidents and near misses. For any one subject, each trial varied on the basis of on-coming vehicle velocity (10-70 mph) and gap size (3-9 sec). These combinations yielded forty-nine conditions which were randomly presented to each participant. There were ten subjects per vehicle type, giving forty total subjects in the experiment. At the conclusion of the experiment participants answered a background driving guestionnaire.

RESULTS

Gap Size by Velocity

In order to convert the complexity of these results into a more coherent and meaningful representational form, initial presentation of findings is through a descriptive graphical structure. The findings of this experiment, following from the number of vehicle types, provided four three-dimensional graphs whose axes correspond to gap size (sec), velocity (mph), and choice to turn left into the stream of traffic, respectively. The patterns of deciding when to turn into a vehicles stream, which varied according to the approaching vehicle type are illustrated in Figures 2 to 5.

Insert Figures 2-5 about here

For the delivery truck (Figure 2), the surface derived from the percentage of decisions to turn left according to combinations of gap size and on-coming vehicle velocity presents the first observation of a paradox which is confirmed throughout the data set. That is, drivers are more reticent to turn left across slower moving vehicles than faster moving vehicles at the same gap size. This is evidenced at the front of Figure 1, in which values recede toward a low at 10 mph and a 3 second gap size. All drivers choose to turn at the highest gap sizes and velocities, while even at a gap size of 9 seconds an increasing number of drivers elect to suspend their turn as the on-coming vehicle velocity drops below 40 mph. The reason for this pattern of turn acceptance is considered when comparison is made across all vehicles. As can be seen, the contour which represents the complete division of drivers at 50%, lies somewhere between the 3 and 4 second gap size at 70 mph and rises to 5 to 6 seconds as velocity consistently drops down to the 10 mph minimum.

For the full size car (Figure 3) the pattern of data is similar to the delivery truck in general morphology. Again, the acceptance of turns by drivers are concentrated at high velocities and large gap sizes. However, the pattern for this vehicle is somewhat more distinct for several reasons. First, there are few turn rejections over a gap size of 7 seconds and the only appreciable number occurs at the lowest velocity. Second the turn rejection frequency is fairly constant over gap size. Although showing a tendency to increase as velocity decreases, the data for gap size 4 seconds from 30 to 70 mph is consistent and the data for gap size 3 seconds from 40 to 10 mph is consistent where drivers choose to reject almost all turns.

For the compact car (Figure 4) the absolute number of turn rejections is decreased. With a single exception, drivers elect to turn left across the compact car at gap size 7 seconds and above across the whole range of velocities investigated. Even below a gap size of 7 seconds, down to a gap size of 5 seconds, there are few turn rejections and then only at the lowest on-coming vehicle velocity. At a gap size of 4 seconds drivers still choose to turn across this size of on-coming vehicle at velocities of 30 mph and greater. It is only at a gap size of three seconds that turns begin to be systematically rejected at the higher velocities.

The final vehicle, a motorcycle (Figure 5) provides a turn frequency which is very similar to the compact car. There is a slight tendency for drivers to turn less frequently at the lower velocities and in the 3 and 4 second gap size conditions. In general however, the picture for these latter two vehicles is quite similar.

Comparing across all four vehicles a number of pattern indicators are evident. First, as mentioned previously, is the tendency of participants to accept more turns at any particular gap size as the velocity <u>increases</u>. This result ran counter to expectations in that vehicles approaching at greater velocities should indicate to drivers the potential greater harm. The second major cross comparison findings is that the frequency of turns decreases as the size of the vehicle increases. This can be seen as a progressive increase in area covered and vertical size of columns across the illustrations 2 to 5. This result was in accordance with both driving experience and the expectation that more opportunities to turn left would be rejected for larger more threatening vehicles.

Collisions

Figures 6 and 7 show the collision frequency associated with the turn figures given above. Given only ten participants per vehicle type, the frequency of collisions should not be considered as representative for a number of reasons. These include the likelihood that subjects may have lowered their criterion of "risk taking" behavior since the simulator provided a novel environment for testing out collisions as opposed to "safe driving," and the fact that the incidence of a collision with a vehicle did indeed affect the behavior of a participant on subsequent trials.

Insert Figures 6 and 7 about here

As can be seen in Figures 6 and 7, there were relatively few collisions that involved the Truck. Of a total of 490 turns performed, only 7 or 1.4% resulted in recorded collision. The pattern of these collisions is of interest. It is clear that the preponderance occur at the upper end of the velocity range investigated and at the lowest gap size chosen. The major distribution shown in the left corner lies in close proximity to the 50% turn decision contour. This latter contour may be a reflection of driver equivocation in the turn decision. It is clear that where an equal number of drivers accept the turn as reject it, the threshold in the investigated space divides the regions into greater or lesser turn certainty. The collision frequency pattern for the Lincoln is similar to that for the Truck with some minor exceptions. First, there are marginally a greater number of collision. Also, there is a single collision at the lowest velocity investigated. However, like the delivery truck, the collision locations are nearly all concentrated at the highest on-coming velocities and smallest gap sizes. For the compact car, there are the greatest number of collisions, distributed across a wider range of conditions compared to any other vehicle type. As can be seen, the dominance of collisions at the lowest gap size and highest velocity is retained, however, there is the propensity for single occurrences of collisions across all velocities at a gap size of 3 seconds, and for many velocities when the gap size is 4 seconds. The motorcycle exhibits the highest density of collisions, again all centered on the high velocity, low gap size configuration.

Experiment 1 is one in a series of investigations concerning driver left-turn decision-making. The data analysis here are preliminary and descriptive representations of a much more complex data matrix. As such it is important to caution against simplistic interpretations that might be drawn. For example, the presentation of a line of traffic of the same vehicle type all equally spaced and all travelling at a consistent velocity is a highly unusual driving condition. Further experimental procedures are examining turns across traffic consisting of multiple vehicle configurations, gap sizes and on-coming velocities. In addition, parallel work is addressing older drivers decisions to turn left, and left-turns at urban intersections. It is only with this detailed information that a full understanding of this hazardous driving maneuver is to be had.

[Integrate the following into above.]

Synthesis of the findings of these experiments provides four, two dimensional surfaces which indicated combinations of conditions in which turns were declined, by subtraction, the combinations of conditions in which turns were accepted, and combinations of conditions in which a collision was recorded. The patterns for turn rejection varied according to the approaching vehicle type and are illustrated in Figures 1 to 4. It is pertinent first, to discuss the patterns observed within one single vehicle and then to deal with comparative patterns across vehicles. It what follows they are examined in order of absolute size.

For the truck, Figure 1, the surface derived from the percentage of decisions not to turn left according to combinations of gap size and on-coming vehicle velocity presents the first observation of a paradox which is confirmed throughout the data set. That is, drivers are more reticent to turn left across slower moving vehicles that faster moving vehicles at the same gap size. This is evidenced at the rear of Figure 1, in which values grow toward a pinnacle at 10 mph and a 3 second gap size. All drivers choose to turn at the highest gap sizes and velocities, while even at a gap size of 9 seconds an increasing number of drivers elect to suspend their turn as the on-coming vehicle velocity drops below 30 mph. The reason for this pattern of turn rejection is considered when comparison is made across all vehicles. From the general shape of the surface presented, the contour which represents the complete division of drivers at 50%, lies somewhere between the 3 and 4 second gap size at 70 mph and rises to 5 to 6 seconds as velocity consistently drops down to the 10 mph minimum. As will be examined in later discussion, this line is considered important in relation to the collisions recorded.

For the large car, the Lincoln, Figure 2, the pattern of data is similar to the truck in general morphology. Again, the rejection of turns by drivers are concentrated at low velocities and low gap sizes. However, the pattern for this vehicle is somewhat more distinct. First, there are few turn rejections over a gap size of 7 seconds and the only appreciable number occurs at the lowest velocity. Second the turn rejection frequency is fairly constant over gap size. Although showing a tendency to increase as velocity decreases, the data for gap size 4 seconds from 30 to 70 mph is consistent and the data for gap size 3 seconds from 40 to 10 mph is consistent where drivers choose to reject almost all turns. These data show a slightly different contour for the 50% decision in that it appears at consistently lower gap sizes throughout the velocity range, see Figure 2.

For the small car, the Chevette, Figure 3, the absolute number of turn rejections is vastly decreased. With a single exception, drivers elect to turn left across the small car at gap size 7 seconds and above across the whole range of velocities investigated. Even below a gap size of 7 seconds, down to a gap size of 5 seconds, there are few turn rejections and then only at the lowest on-coming vehicle velocity. At a gap size of 4 seconds drivers still choose to turn across this size of on-coming vehicle at velocities of 30 mph and greater. It is only at a gap size of three seconds that turns begin to be systematically rejected at the higher velocities. As a consequence, the 50% contour line has been attenuated yet again in this type of on-coming vehicle and its origin here lies below the lowest 3 second gap size investigated for the two highest velocities of 60 and 70 mph.

The final vehicle, a motorcycle, Figure 4, provides a no turn density very similar to the small car. There is a slight tendency for drivers not to turn left as frequently at the lower velocity and also as the velocity increments along the 4 second gap size condition. In general however, the picture for these latter two vehicles is very similar

(Question: What is their Actual Frontal Surface area?)

Comparing across all four vehicles we see a number of obvious patterns. The first, as mentioned above is the tendency to reject more turns at any particular gap size as the velocity decreases. This is somewhat counter-intuitive as it might be expected that individuals would consider that greater on-coming velocities would provide potentially greater harm if intercepted. The second major cross comparison findings is that the propensity to turn decreases as the size of the vehicle increases. This can be seen as a progressive decrease in area covered and vertical size of columns across the illustrations 1 to 4. This result accords with intuition since it is reasonable to reject more turns in front of larger and more threatening vehicles that it is the smaller and more benign vehicles.

Figures 5 to 8 show the collision frequency association with the no turn distributions given above. As this was a between subject design with ten subjects per vehicle type, the absolute level of collisions expressed as a percentage should not be considered as representative, as the grain size is insufficient in this small sample. However, the pattern of distribution of these collisions is considered most relevant.

As can be seen in Figure 6, there were relatively few collisions that involved the Truck. Of a total of 490 turns performed, only 7 or 1.4% resulted in recorded collision. The pattern of these collisions is instructive. It is clear that the preponderance occur at the upper end of the velocity range investigated and at the lowest gap size chosen. The major distribution shown in the left corner lies in close proximity to the 50% turn decision contour. We might take this latter contour as a reflection of driver equivocation in the turn decision. It is clear that where an equal number of drivers accept the turn as reject it, we are seeing the threshold in the investigated space that divides the regions of greater or lesser turn certainty.

The collision frequency pattern for the Lincoln is similar to that for the Truck with some minor exceptions. First, there are marginally a greater number of collision. Also, there is a single collision at the lowest velocity investigated. However, like the Truck, the collision locations are nearly all concentrated at the highest on-coming velocities and smallest gap sizes.

For the Chevette, there are the greatest number of collisions, distributed across a wider range of conditions compared to any other vehicle type. As can be seen, the dominance of collisions at the lowest gap size and highest velocity is retained, however, there is the propensity for single incidences of collisions across all velocities at a gap size of 3 seconds, and for many velocities when the gap size is 4 seconds.

The motorcycle exhibits the highest density of collisions, again all centered on the high velocity, low gap size configuration.

As can be seen from the illustrations, drivers turning left across the truck were almost uniformly successful when the inter-vehicle interval exceeded six seconds. Between three and five seconds successful turns and no-turn decisions were equally divided with the preponderance of turns at the upper velocities giving way to a reciprocal picture for no-turn decisions at the lower velocities. The majority of collision events are scattered along this latter boundary with a tendency to increase with on-coming vehicle velocity. The motorcycle presented a similar pattern except that the temporal gap chosen as safe proved to be 5 seconds rather than six seconds as with the truck. Again, below the five second condition subjects choose not to turn across motorcycles at the lower velocities, i.e., 10-40 mph. As with the truck, collisions increased at higher velocities only this data is more often interspersed by successful turns. For the large car a similar pattern can again be seen except the time gap chosen was approximately seven seconds and that turns above this gap were not always taken, nor were they always successful. What stands out here is the reticence of drivers to turn across the large car. Where the percentage of rejected turns (52.4%) were over half the presented opportunities. Again, collisions were scattered largely along the division line between the turn decisions, although with this vehicle, there is not so strong a trend toward collisions at the higher velocities. The pattern for the small car is similar to that for the truck, except that as with the motorcycle, drivers were less reticent to turn across the small car at the five and six second gap times.

EXPERIMENT 2

Participants

Forty participants volunteered from current and retired faculty at the University of Minnesota and from retirement communities around the Twin Cities. Their mean age was ____and it ranged from ____to ____. The number of years driving for this age group was ___. The numbers of males and females was approximately equal, a total of ___female and ____ male participated.

Procedures

Information presentation and procedures are the same as in experiment one.

RESULTS

Gap Size by Velocity

Collisions

Older vs Younger Drivers

DISCUSSION

General Outline of Discussion

I. What were the primary findings?

II. How do these results apply to the real world and in what instances are they not so generalizable?

III. What is future research is planned to extend the present work?

[What were the primary findings?]

The choice to turn left is based in part on the size of the vehicle as well as the gap between vehicles and their velocity.

Drivers are more likely to turn left if those vehicles are traveling at a higher velocity.

There are quite distinct differences between younger and older drivers patterns of responses to turn left which reflect a more cautious strategy by older drivers.

The likelihood of an accident increases as a function of increased velocity and decreased gap size.

Perceptually, it was found that neither gap size nor vehicle velocity was the basis for deciding to turn left. From the pattern of response surfaces, an interplay between these information sources was evidenced.

The present results indicate that in general drivers did not initiate turns dependent upon the physical parameters of on-coming vehicle distance (see Figure 7), on-coming vehicle velocity, on-coming gap size in a consistent manner. Although these factors appeared to have some influence to a greater or lesser degree (e.g., see inter-vehicle gap times), drivers appeared to use some embedded information extracted from these physical values. Initially, it was proposed that higher order perceptual properties such as rate-of frontal surface area expansion indicated so that what information combinations and when such information influences drivers' decisions to turn left can be determined.

[How do these results apply to the real world and in what instances are they not so generalizable?]

While the verbal instructions given to participants emphasized making turns when they thought that it was safe to do so, some may not have heeded these suggestions and adopted other risk-taking sets given the novelty of simulator driving. For example, a shift in risk taking behavior tended to accompany the collisions between participants and on-coming vehicles for a variable number of trials before returning to "normal" turning. In addition, perceptual learning as a function of the number of trials may have influenced the pattern of results. As with any set of results, caution in interpretation is conceded, however, randomization of trial conditions and randomization of participants to conditions assisted in controlling for parts of these concerns.

What is future research is planned to extend the present work?

In this line, using relatively simpler experimental paradigms (e.g. Schiff & Detwiller, 1979; Cavallo & Laurent, 1988), the rate-of-change and physical parameter relationships for deciding to turn left are being further examined in both simulation and on-road investigations.

We are completing several experiments on a optical dependent measure called time-to-arrival which we hope will provide convergent evidence for the perceptual basis of turning left.

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FIGURE CAPTIONS

Figure 1. Composition of the hardware and software of the University of Minnesota fixed-base simulator.

Figure 2. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for an delivery truck as the on-coming vehicle.

Figure 3. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a full size as the on-coming vehicle.

Figure 4. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a compact car as the on-coming vehicle.

Figure 5. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a motorcycle as the on-coming vehicle.

Figure 6. Total number of collision events by vehicle type and on-coming vehicle velocity.

Figure 7. Total number of collision events by vehicle type and gap size between on-coming vehicles.

Figure 8. Inter-vehicle distance as a function of gap size and vehicle velocity expressed as a percentage of the longest distance encountered. The earlier data in Figures 2-5 indicated that subjects cannot have exclusively used gap time or on-coming vehicle velocity to initiate the turn decision. This illustration similarly rejects the exclusive use of physical distance as the determinant of the turn decision.

Figure 9. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for an delivery truck as the on-coming vehicle.

Figure 10. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a full size as the on-coming vehicle.

Figure 11. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a compact car as the on-coming vehicle.

Figure 12. Percentage of decisions to turn left versus on-coming vehicle velocity and inter-vehicle gap size. This figure shows data for a motorcycle as the on-coming vehicle.

Figure 13. Total number of collision events by vehicle type and on-coming vehicle velocity.

Figure 14. Total number of collision events by vehicle type and gap size between on-coming vehicles.

Figure 15. The differences in percentages between older and younger drivers for vehicle type; delivery truck.

Figure 16. The differences in percentages between older and younger drivers for vehicle type; full size car.

Figure 17. The differences in percentages between older and younger drivers for vehicle type; compact car.

Figure 18. The differences in percentages between older and younger drivers for vehicle type; motorcycle.

General Outline

I. What statistics support the hazardness of the left turn?

   a.) older drivers (Staplin? TRB? see Evans book)

   b.) general population (refs)

   c.) motorcycle drivers (Hurt et al)

II. What is the left turn? (See Acc Anal Paper)

III. What is the informational basis of the left turn? [Literature Review]

   a.) psychophysical approach

   b.) informational approach

IV. What is our primary research questions?

   a.) gap-size vs. velocity question

   b.) vehicle type

   c.) younger patterns (Exp. 1)

   d.) older patterns (Exp. 2)

   e.) older vs. younger differences (Exp. 1 vs 2)