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The Perception of Arrival Time for Different Oncoming Vehicles at an Intersection

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We make an appeal to bring the theoretical tools of ecological psychology to focus on road-traffic accidents that result from making left turns. Following a review of previous arrival-time literature, we report an experiment that was conducted in a fixed-base driving simulator to determine the perceptual basis for judgments to turn left. We manipulated the arrival time (T_a) of an oncoming vehicle, the viewing distance to that vehicle, and the type of oncoming vehicle. Forty-eight participants were randomly assigned to a group in which a motorcycle, a compact car, a full-size car, or a delivery truck represented the oncoming vehicle. There were equal numbers of male and female participants in the four groups. As T_a was increased, underestimation of vehicle T_a also increased. Significant main effects were found for T_a, gender of participants, vehicle type, and viewing distance; significant effects were also found for interactions for gender by T_a and gender by vehicle type. Men and women differed in their accuracy of judgments for vehicle types; men were more accurate in estimating the arrival of delivery vans and motorcycles than women. The accuracy of T_a estimation for the type of the approach vehicle and distance removed suggests that participants used vehicle-size information in their judgments. We present a discussion of a number of "disappearance" methodological issues and research applications.

In an era of economic stringency, there is progressively more reference to "accountability." In common parlance, this is the perceived value of return on investment. Such constraints are being visited more and more on the scientific

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enterprise. There is an increasing societal requirement to "justify" the support given. In an analogical sense, accountability can be rendered into the theoretical realm. Thus, science continually investigates the return that is recouped from intellectual investment. This investment is theory, the return is presumably a progressively more veridical account of reality. There is much to dispute here, and many of us will have the opportunity to do so later. But ecological psychology has protested a superior theoretical accountability over existing paradigms by its emphasis on situated action and the criticality of considering environment–actor interactions. If this protestation is valid, ecological psychology must submit its theoretical constructs to the very crucible that it purports to embrace—the real world. The question then becomes, which facet of the real world is the one to address?

If the ecological approach can provide us with important answers, we must pose important questions. With respect to society's resources, the process of selection or triage is actively practiced in everyday society when we, or our representatives, collectively decide where to place limited resources. As resources diminish, accountability increases and societal triage becomes a critical process in deciding, as Aristotle noted, how and who we "create as our future selves." As we survey contemporary society, triage strategy depends directly on the glasses through which we look. Futurists attempt to anticipate the potential sources of global catastrophe and ameliorate their future destructive influences. As we lower our temporal horizon, we encounter everyday problems that, through their very ubiquity, seem mundane and somewhat immalleable. However, because a problem is pervasive does not mean it is insoluble. In simple terms, we need to evaluate the things that kill and injure people. In the United States, as is true for most countries of the world, more life is lost through road-traffic accidents than any other source (Transportation Research Board, 1990). The loss of an individual human life is a tragedy, but road-traffic accidents do not merely remove life, they more frequently remove functional capability. The estimated total cost of road-traffic accidents in the United States is $89 billion per year (National Safety Council, 1991). Hence, addressing the problem of road-traffic accidents is nontrivial in societal terms and, as it turns out, also in theoretical terms. Therefore, if ecological psychology is to fulfill its promise, we must be able to use it in the real world, and it must prove itself applicable in the machine world (Flach, 1989). If we can effectively use ecological psychology, it can render signal service to society and provide a case for accountability far beyond any facet of scientific psychology that has yet been achieved. There are other reasons for such work; it is arguable that some of the earliest roots of the ecological approach lie in an examination of driver behavior (see Gibson & Crooks, 1938). There are those today who perpetuate this line of research (Schiff & Arnone, in press; Schiff & Oldak, 1993). As Gibson pointed out, driving a car is locomotion by way of a device, and who better to address dynamic spatiotemporal navigation than those steeped in the ecological paradigm?

THE LEFT TURN

We must not assume that all vehicle accidents are tractable to investigations within the ecological paradigm. As much as anything else, science is the art of the soluble, and deciphering the problems that are amenable to solution is, alone, no small task. By our focus here, we believe that the left-turn question is one that can be addressed by ecological principles and knowledge applied from those principles could result in the reduction of actual accidents. There are many reasons for this conclusion. When waiting to turn left across traffic, we seek to synchronize the passage of our vehicle with a space in the oncoming stream. The principal information on which such a decision is predicated is the movement of vehicles in depth. In consequence, tau (τ) would be, a priori, a critical cue on which to found subsequent action. In-depth investigation of left-turn accidents suggests that older drivers are more involved in this maneuver than others (Evans, 1991). Regarding oncoming vehicles, there is an overrepresentation of motorcycles. But within the motorcycle population, there is an underrepresentation of police motorcyclists and, somewhat paradoxically because they represent low contrast, Hell's Angels (Hurt, Ouellett, & Thom, 1979). Finally, the left turn has a high incidence of accidents for the percentage of drivers performing the maneuver. Forty-five percent of vehicle collisions involve a left-turning vehicle, whereas only 10 to 15% of all traffic turns left (Cottrell, 1986). In consequence, we know something about the visual information involved, the type of individuals for whom this maneuver is a problem, and the type of vehicles that represent this problem. There is a great need to further research the left-turn problem.

EMPIRICAL EVALUATION OF ARRIVAL TIME

Because understanding the relative contribution of driver error to accidents is one basis for prevention, a decomposition of the left-turn maneuver logically begins with an examination of the perceptual information available to the driver (Gibson & Crooks, 1938; Hills, 1980; Lee, 1976; Schiff & Arnone, in press). The "disappearance paradigm" is a useful experimental strategy for determining the perceptual information on which driving performance is based (Schiff & Detwiler, 1979). It is this approach that is reviewed, following, as a precursor to an experimental evaluation of simulation-based time-to-contact. In general, an experiment in which participants are asked to judge when an object or vehicle will reach them (if it had not been removed from view) is considered a study in arrival time. However, it is important to provide specific definitions as a basis for examining contemporary findings. The length of time between visual removal and collision or near contact with an individual is known variously as *time-to-go* (Carel, 1961), *time-to-contact* (Lee, 1976), *time-to-coincidence* (Groeger & Brown,

1988), *time-to-collision* (Brown & McFaddon, 1986; Purdy, 1958, p. 68; Schiff, 1965), *time-to-arrival* (Schiff & Oldak, 1990), *arrival time* (DeLucia, 1991a; Schiff & Oldak, 1990), and *time-to-passage* (Kaiser & Mowafy, 1993). The distinction between each term centers on whether an approaching object or a person approaching an object is on a collision course or not. Terms that refer to coincidence or passage refer to objects that will pass, or be passed, by the observer. Labels such as *go*, *collision*, and *contact* specify imminent collision. *Arrival time* is a more general term that encompasses a greater set of informational events, whether or not one or more objects will collide with or pass by an observer. Schiff and Oldak (1990) called for the use of arrival time because a proliferation of terms has confused empirical and theoretical work. Arrival time (T_a) is used here, and recommended for future work.

Beginning with Knowles and Carel (1958), empirical T_a studies have found that as T_a increases, so did a tendency for underestimation of its coincidence by observers; and as T_a increased, the variability of observer estimates increased accordingly. Figure 1 summarizes the results from previous studies with the T_a paradigm and shows a simple fit of the combined means from these experiments. It is striking that there is a consistent underestimation of T_a, despite differences in experimental manipulation such as: the presence or absence of texture (Schiff & Detwiler, 1979, Experiment 1), driving experience (Cavallo & Laurent, 1988), degree of the approach eccentricity to self (Schiff & Oldak, 1990, Experiments 1, 3, 4) viewing time, viewing distances, and object size. The method-for-stimulus presentation also varied considerably and included: actual vehicles (Cavallo & Laurent, 1988), film (McLeod & Ross, 1983; Schiff & Oldak, 1990), shadow graph (Carel, 1961), animated table-top photography (Schiff & Detwiler, 1979; Schiff & Oldak, 1990, Experiment 4), and combinations of visual and auditory information (Schiff & Oldak, 1990, Experiment 1). Although the descriptive pattern of results from these collective studies appears to bear a robust similarity, the specific manipulations that brought about these convergent results varied.

INFORMATION FOR T_A JUDGMENTS

A brief history of attempts to link the perception of τ and other physical characteristics of approaching objects in the environment to human perceptual judgments is instructive. Initially, Schiff and Detwiler (1979) sought to determine whether observers used distance, velocity, or distance divided by velocity (d/v) in their judgments. Schiff and Detwiler (1979) concluded that judgments of T_a were based on a two-dimensional rate of angular-size-change invariant, despite other lower order sources of information being available (i.e., distance, velocity, or absolute angular size). This result was also confirmed by Yakimoff, Mateeff, Ehrenstein, and Hohnsbein (1993). Other researchers have derived the virtues of τ, that is, $\theta/d\theta/dt$, or the visual angle of an object divided by the rate

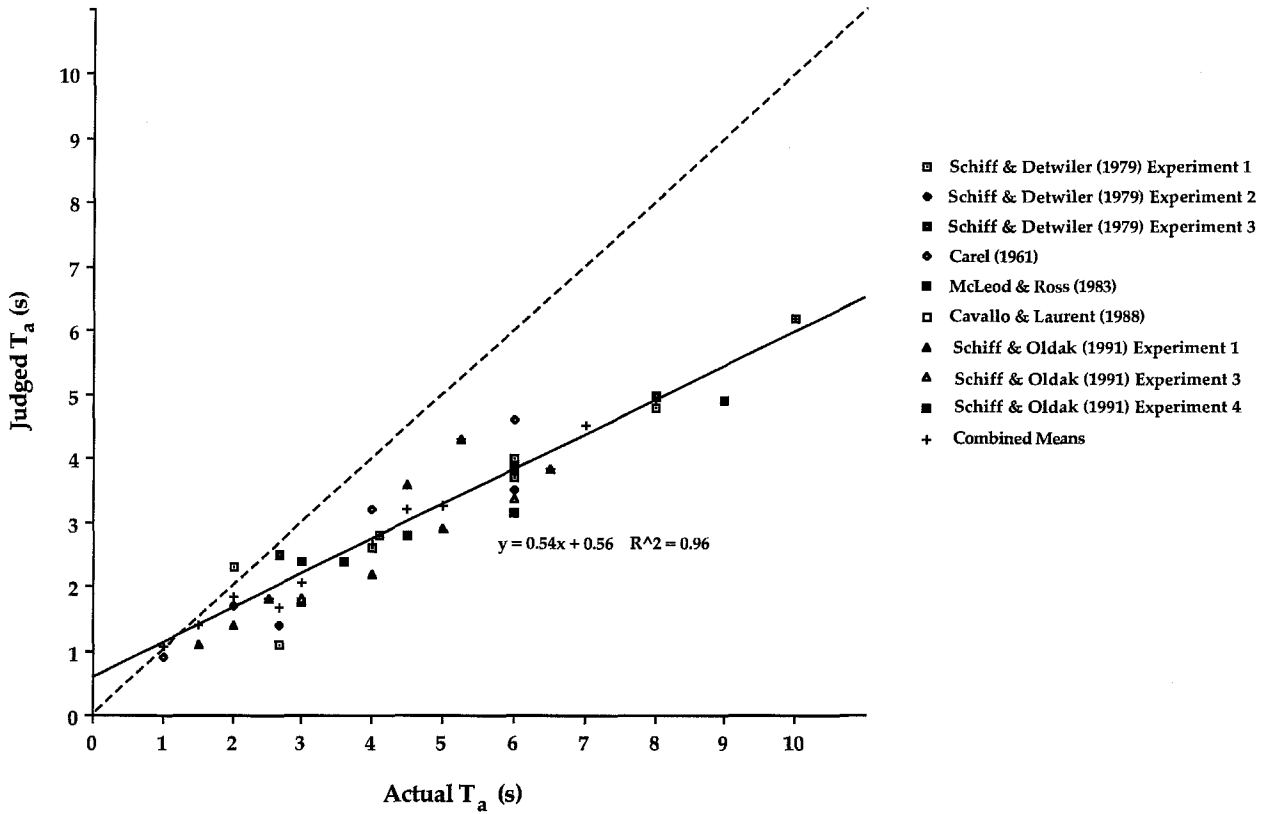

FIGURE 1 Judged T_a estimated in prior research. Cavallo and Laurent's (1988) data were averaged because an equal number of participants were present in each group.

of expansion (e.g., Bootsma & Peper, 1992; Kaiser & Phatak, 1993; Lee, 1980; Regan, Hamstra, & Kaushal, 1992). In approaches that are of a constant velocity, τ is the inverse of the rate of dilation of an object, and it provides information for time until arrival. Studies that followed Schiff and Detwiler (1979) implicitly assumed that this information is perceived and then sought to test whether other physical characteristics of objects, viewing conditions, and different population samples reduced the accuracy of judgments. McLeod and Ross (1983) found an effect for velocity, although it was confounded with T_a. Cavallo and Laurent (1988) manipulated visual field, binocular versus monocular viewing, speed, and driving experience. They found that monocular vision, being a beginner, and field of view reduced the accuracy of T_a judgments. Schiff and Oldak (1990) found that tangential paths were judged more accurately than head-on paths. Schiff, Oldak, and Shah (1992) found that younger observers and nonmetric estimates (the disappearance methodology) of T_a were more accurate, and older observers and indirect estimates (e.g., verbal estimates of velocity) were less accurate. In conclusion, some variables affected the accuracy of estimations more than others.

THE PROBLEM

From our previous research on the left turn, we observed that both younger (Hancock, Caird, Shekhar, & Vercruyssen, 1991) and older (Hancock & Caird, 1993) drivers chose to turn more frequently in front of smaller vehicles, compared in a range of velocities, than in front of larger vehicles, that is, given the choice to turn or not to turn into a stream of traffic. Physical motorcycle characteristics, and the lack thereof, have also been found to have an effect on the rates of accident involvement (Wulf, Hancock, & Rahimi, 1989). In addition, the likelihood of accident involvement based solely on vehicle models that vary in physical size and material composition is well known by actuarial analysts of insurance companies. For example, motorcycles have 17 times the mileage death rate than other vehicle types (National Safety Council, 1991). In our previous left-turn research, the differential effect of size on judgments to turn left could not be explained by the perception of the inverse of the rate of expansion of a vehicle alone. In the first experiment performed by Schiff and Oldak (1990), an effect for vehicle type (truck, sedan, van, and station wagon) was apparently not explicitly tested. The perception of τ would predict an equivalence between estimates of different-sized automobiles. In our research, we sought to test whether τ or vehicle size characteristics affected the accuracy of T_a judgments. An unsignalized left-turn intersection was used because it was our intention to complement our previous research and to speak to a known problem where loss of life and capability occurs. Within the intersection, the place where the vehicle was removed was thought to be scenario-relevant; thus,

only within the intersection and on the highway before the intersection were manipulated. As found previously, it was expected that estimated T_a for vehicles would be underestimated. We also predicted that as absolute vehicle size increased, underestimation of T_a would either remain the same if τ was used for T_a estimates, or underestimation would progressively increase if vehicle size affected judgments. As found previously (McLeod & Ross, 1983; Schiff & Oldak, 1990), a gender effect was expected. Effects for gender were tested because accident rates for either sex differ (Evans, 1991).

METHOD

Participants

Forty-eight graduate and undergraduate students (24 men, 24 women) volunteered to participate in the experiment. Their ages ranged from 18 to 44, with a mean of 26.4. All were licensed to drive and had normal or corrected-normal vision at the time of testing.

Information Presentation

Participants were seated in a fixed-base 1990 Honda Accord. They were asked to judge the arrival times of vehicles within a traffic-intersection scene, projected by an Electrohome EP–3000™ onto a 150-in. diagonal screen located 7 feet 4 in. (2.4 m) in front of them. The generation of driving scenes was performed by a 80386, 33 MHz computer, running the XTAR–Falcon 2000™ graphics system. The hardware for the timing inputs included a Linemaster switch and Computer Boards™ A/D card. Computer animation of each traffic-scene component began with collections of polygons created in AutoCAD® and transformed through several intermediary formats to result in roadways and terrain with specific coordinates in the projected scene. The dimensional layout for the roadways, vehicles, and intersection used in this experiment was in accord with the *Manual of Uniform Traffic Control Devices* standards (U.S. Department of Transportation: Federal Highway Administration, 1988). Using C, XTAR libraries, and XTAR programs, the pieces of the visual scene were integrated and animated. Figure 2 provides a representation of the layout of the hardware for the driving simulator. Figure 3 represents an approximation of the scene content from the urban, unregulated intersection used in this experiment. The polygons, or scene pieces, did not have texture per se, although perspective depth cues were integral to the intersection. The color compositions of the approaching vehicles were: motorcycle—blue helmet, white rider, and red cycle; compact car—blue with gray windshield; full-size car—red with gray windshield; and delivery van—dark brown and styled to represent an AMC Motors U.P.S. Van.

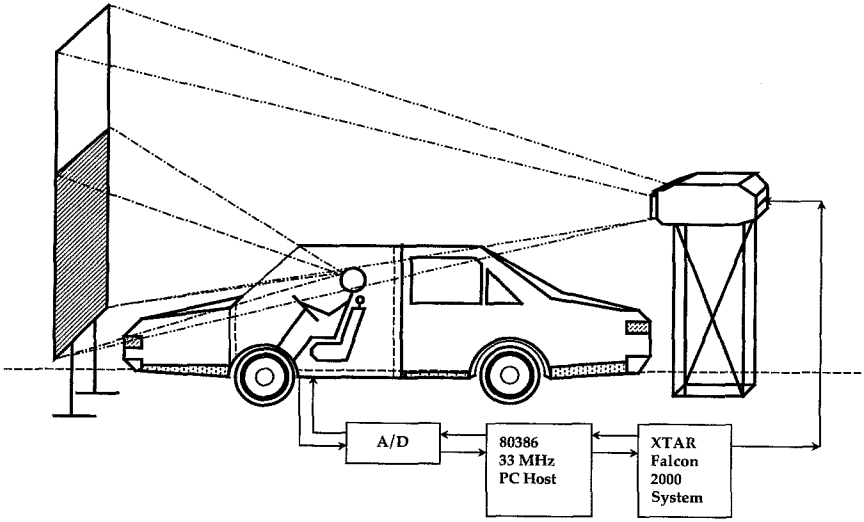

FIGURE 2 Layout of the driving simulation system with components of computer hardware. Drawing is not to scale.

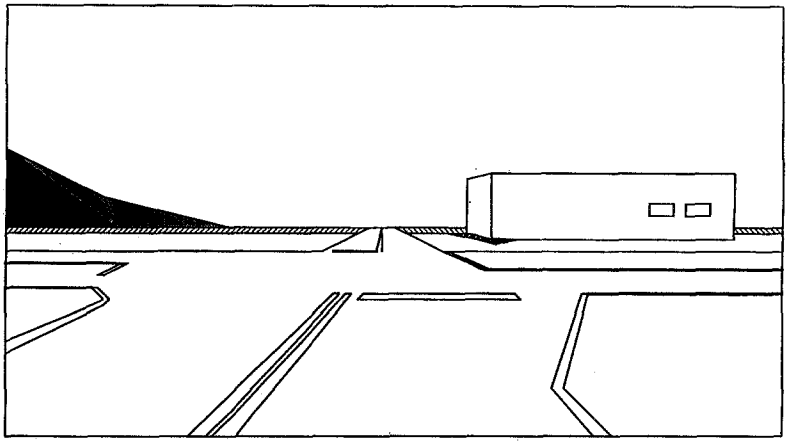

FIGURE 3 Background intersection at approximately 30 feet (6.14 m) back from the position of an observer during the experiment. Black roadways, white lines, a gray building with light green windows, and a yellow and brown alternating ground plane were presented.

Procedure

Participants were seated in the simulator and given instructions about what they would see and how they should interact with the computer-generated intersection scene when vehicles approached them. A participant's car was stationary at a nonregulated stop line of the intersection scene. They were asked to press a

hand switch when the front of the approaching vehicle in the opposite lane reached the front of their vehicle. Forty-eight participants were randomly assigned to four conditions in which a motorcycle, compact car, full-size car, or delivery van was the oncoming vehicle. An equal number of men and women were assigned to each condition. Four actual T_a values (1, 3, 5, and 7 s) were crossed with two distance-removal locations, either 100 feet or 200 feet (30.5 m and 60.9 m), where the approaching vehicle disappeared at that respective distance. An additional T_a value of 2 s was added to the 100-feet (30.5 m) removal condition to complement the range of arrival times included in the experiment. Vehicle velocities were varied so that T_a values were met for each distance. Table 1 specifies the parameters for information for the 9 trial types used. Participants performed 9 practice trials, followed by 27 experimental trials, in which within a given block of 9 test trials, the order of presentation was randomized for each participant.

RESULTS

Estimated T_a was converted to a percentage of actual T_a for analysis and comparison purposes. A 2 × 4 × 2 × 5 (Gender × Vehicle Type × Distance Removed × T_a) analysis of variance (ANOVA) was computed on percent accuracy. Gender and vehicle type were between-subjects variables, whereas distance and T_a were within-subjects variables. Main effects were found for all between- and within-subjects variables. Two significant, two-way interactions were found for Gender × Vehicle Type and Gender × T_a.

T_a Results

As expected, participants underestimated actual T_a, and underestimation increased as T_a increased, $F(4, 156) = 33.76$, $p < .001$. Figure 4 illustrates the increased underestimation of T_a and an increased variability in judgments at the longer arrival intervals that has been found previously (e.g., Schiff & Detwiler, 1979). Overall, the magnitude of underestimation appears to be similar to previous studies (see Figures 1 and 4). The slope of a simple fit of the data in Figure 1 was 0.54, whereas the slope in Figure 4 was 0.56. The combined means of Figure 1 include the means from this experiment. A number of methodological, statistical, and population-sample differences may account for the degree of accuracy found here and in other studies. Vehicles approached the observer to the left of center or slightly tangentially, which may have yielded greater accuracy (Schiff & Oldak, 1990; Todd, 1981). Previously, researchers (Schiff & Detwiler, 1979; Schiff & Oldak, 1980) analyzed just the first few trials, whereas all trials were included in this analysis.[1] The Schiff and Detwiler (1979) studies

[1]Evidence suggests that the first few trials were ecologically valid estimates of what a driver might encounter in traffic situations.

TABLE 1
Trial Information Composition

T_a Seconds	Exposure Time Seconds	Total Elapsed Time Seconds	Start Distance Feet	Start Distance Meters	Final Distance Feet	Final Distance Meters	Velocity Feet S^{-1}	Velocity Meters^{-1}	Velocity mph	Velocity kph	Error Feet	Error Meters
1	3	4	400	122	100	30.5	100.0	30.5	68.0	109	7.5	2.3
1	3	4	800	243	200	60.9	200.0	60.9	136	218	15.1	4.6
2	3	5	250	76	100	30.5	50.0	15.2	34.0	36	3.8	1.2
3	3	6	200	61	100	30.5	33.3	10.1	22.7	73	2.5	0.76
3	3	6	400	122	200	60.9	66.7	20.3	45.3	73	5.1	1.6
5	3	8	160	49	100	30.5	20.0	6.1	13.6	22	1.5	0.46
5	3	8	320	97	200	60.9	40.0	12.2	27.2	44	3.0	0.91
7	3	10	143	43	100	30.5	14.3	4.3	9.7	16	1.1	0.33
7	3	10	286	87	200	60.9	28.6	8.7	34.0	54	2.2	0.67

Note. This is an information composition of the nine trial types used in the experiment. Error represents the accuracy or likelihood that a vehicle will be drawn within the constraints of a place in space and time, given the limitation of the computer graphics system to place it there.

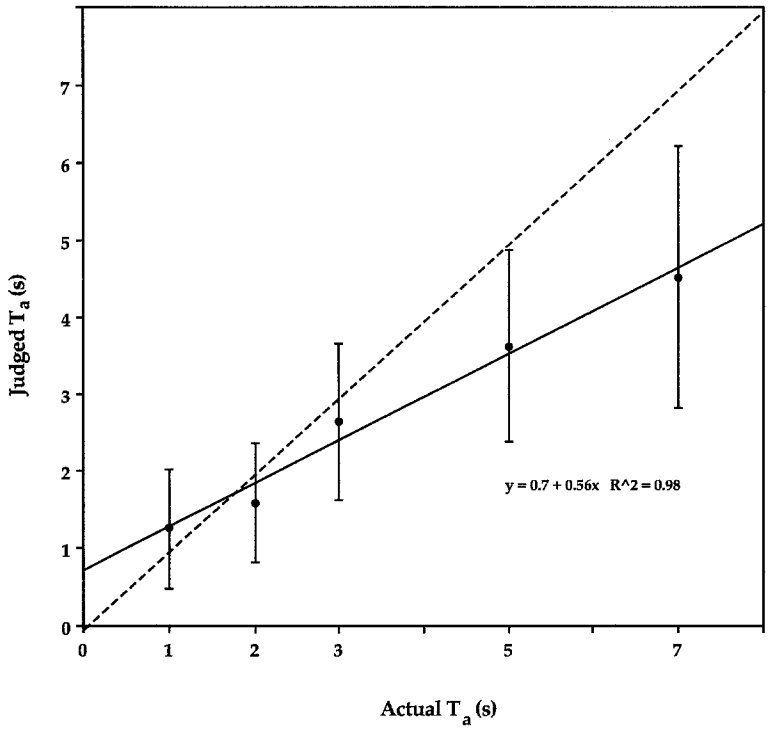

FIGURE 4 Judged T_a as a function of actual T_a averaged for four experimental conditions. Error bars indicate standard deviation.

used women primarily (28 of 36 in Experiment 1, 18 of 24 in Experiment 2, and 9 of 16 in Experiment 3). Women tend to underestimate T_a more than men (see Gender section, following). Furthermore, the sample population of this study was predominantly composed of younger drivers, who are more likely to be accurate than an older sample (see Schiff et al., 1992). Cultural and risk-taking differences may exist between French, British, New York, and Minneapolis–St. Paul drivers that may have contributed to the differences in accuracy.

Proportional error magnitudes were less than Schiff and Detwiler's (1979) reports of 0.34 at 4 s, 0.39 at 6 s, and 0.37 at 8 s. In our study, the proportional error magnitude for 1, 3, 5, and 7 s was 0.25, 0.12, 0.28, and 0.35, respectively. We conclude that, as a function of T_a, absolute proportional error also increased. Similarly, the same data can be compared with other studies using the coefficient of variation (CV; Stoffregen & Riccio, 1990, p. 267). The CV is the mean divided by the standard deviation, and it has been used to argue for consistency in performance. For example, the CVs of Lee, Young, Reddish, Lough, and Clayton (1983); Stoffregen and Riccio (1990); and Schiff and Detwiler (1979) were 0.02 s, 0.18 s, and 1.5 s, respectively. Our CV was 2.17 s.

The ordering of CVs may reflect the type of media used to display a loom (real, film, or computer-mediated) and the necessity for action (punching a falling ball, postural adjustment, and anticipating the arrival of a vehicle). We return to this issue in the Discussion section. In general, these data support the view that participants become more variable with increases in actual T_a but they also become more conservative, that is, they underestimate T_a more.

In our experiment, we examined the restricted T_a intervals at the low end, that is, 1-s period, which allowed some insight into conditions in which only a brief interval is given to the driver to respond to T_a information. In this condition, analogous to a quick glance, participants overestimated T_a. Interestingly, at $T_a = 1$ s, the participants overestimated T_a as a group, although this overestimation may have been affected by the inclusion of an extreme velocity to meet the required T_a (see Table 1). It is important to note that combinations of physical characteristics (e.g., removal distance and T_a) variables could only be manipulated two at a time, which leaves other physical variables confounded (e.g., velocity and T_a). It was shown previously (Schiff & Oldak, 1990, Experiment 3) that velocity did not significantly affect judgment accuracy when held constant and T_a was varied. However, accuracy was slightly better at higher velocities, which was also found in McLeod and Ross (1983). Carel (1961) used a T_a of 1 s, Schiff and Oldak (1990, Experiment 1) employed an interval of 1.5 s, and Stoffregen and Riccio (1990) found subjects responded late for T_a intervals of 0.5 s and 1.0 s. However, only Schiff and Detwiler (1979) found overestimates at 2.0 s. Van der Horst (1991) suggested that at lower T_a values, subjects would be more accurate. His erroneous predictions arose from extrapolating Steven's psychophysical power function to data with longer arrival times (Cavallo & Laurent, 1988; McLeod & Ross, 1983; Schiff & Detwiler, 1979). The overestimations at lower T_a values found here and by Stoffregen and Riccio (1990) suggest that participants have difficulties within this region of T_a. Whether overestimation represents a significant driving problem has yet to be confirmed because the observation here was made at a high approach velocity, rarely seen in everyday driving. For left turns, T_as of this range logically preclude safe responses.

Distance

We found a significant main effect for distance, $F(1, 156) = 42.76$, $p < .0001$. The inclusion of two distances for removal of 100 and 200 feet (30.5 and 60.9 m) tested the effect of having a vehicle within the intersection, and further back from it (Figure 5). Estimates were more accurate for vehicles that were closer, that is, inside the intersection, than for vehicles that were removed at a greater distance, or further down the road (with the exception of $T_a = 7$ s, for a removal distance of 100 feet). At each distance, the length of viewing time was constant (3 s) and changes in vehicular expansion of the vehicle closer to an observer resulted in more accurate judgments. These results contrast with Schiff and

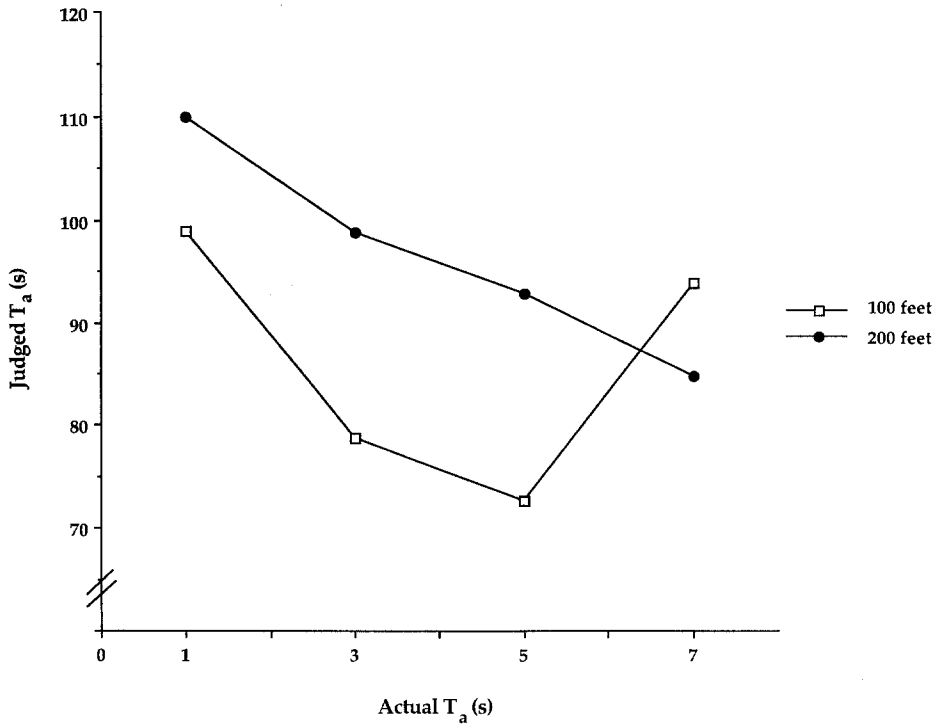

FIGURE 5 Removal distances for estimated and actual T_as.

Detwiler's (1979, Experiment 3) results of no effect for two different removal distances. Our results suggest that other information besides τ was used for estimations. If drivers were using τ to estimate T_a, the accuracy of judgments at either distance should not have been different. Because the vehicles were still some distance from the observer, changes in the rate of expansion may not have reached the detection threshold. Thresholds for detecting rates of change at the two distances and alternative interpretations of our results are expanded in the Discussion section.

Gender

Judgments of vehicle T_as by men and women significantly differed, $F(1, 39) = 12.6$, $p < .0001$. Also, a Gender × T_a interaction (Figure 6) was significant, $F(4, 39) = 4.03$, $p < .003$. Tukey Honestly Significant Difference (HSD) post hoc comparisons revealed that men were significantly more accurate than women at judging the actual vehicle T_a of 7 s ($p < .05$). McLeod and Ross (1983) and Schiff and Oldak (1990) also found that men underestimated T_a to a lesser degree than did women. Explanations for the difference between men and women on this

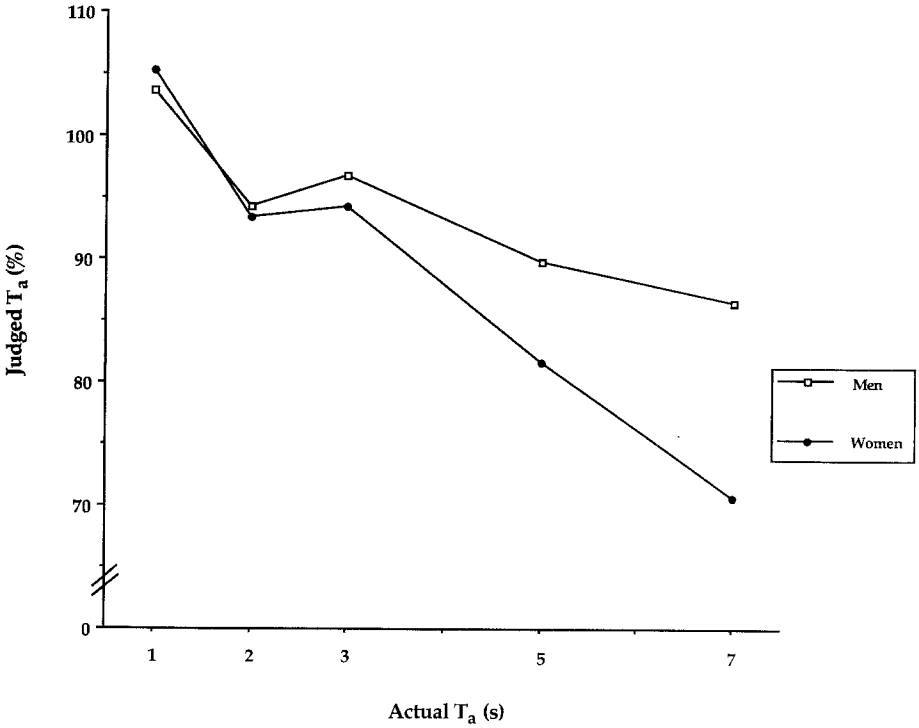

FIGURE 6 Male and female T_a judgments as a function of actual T_a.

task include a risk-taking inference, based on the observation that men were more likely than women to turn into gaps between vehicles (Ebbesen, Parker, & Konečni, 1977; Hills, 1980) and to proceed through yellow lights (Konečni, Ebbesen, & Konečni, 1976). Schiff and Detwiler (1979) suggested that the general level of activity experience may influence estimates in which men are assumed to have more experience. Other plausible reasons for a difference between male and female T_a estimates could be attributed to hormonal and structural differences in the brain, however, these variables are clearly beyond the scope of this study.

One of the most pervasive individual differences where men perform better than women is on certain spatial tasks (Kimura, 1992); one of which is target-directed motor skills (i.e., guiding or intercepting objects). However, attempts to link specific spatial-ability measures (e.g., spatial orientation or visualization) with the individual differences found with T_a (Schiff & Oldak, 1990, Experiment 4) have not been successful. The reason advanced for this result was that spatial-ability measures appear to be related to static displays, but not necessarily to dynamic displays. Schiff et al. (1992) expanded this contrast to

a distinction between metric and nonmetric kinds of judgments. Metric judgments are those that involve verbal estimates of velocity or distance (e.g., Scialfa, Guzy, Leibowitz, Garvey, & Tyrell, 1991), whereas nonmetric estimates are, like T_a, direct. Another metric or indirect method of assessing time perception is reproduction of time intervals.

Attempts by Schiff and Oldak (1990) to link time estimation and gender differences in T_a estimation were also inconclusive. Schiff and Oldak again found that time estimation through interval reproductions and T_a are two different kinds of tasks. Hancock and Vercruyssen (1994), in reviewing Schiff and Oldak's (1990) conclusions that gender differences in T_a proved unrelated to an ability to estimate duration, observed that Schiff and Oldak used time *reproductions* to compare with results from the T_a procedures. This is an inappropriate comparison because estimates of T_a represent an unfilled production procedure in time estimation (e.g., see Hornstein & Rotter, 1969). There is a weak relationship between production and reproduction because reproduction is thought to rely primarily on memory, whereas production does not. In consequence, Hancock and Vercruyussen argued that Schiff and Oldak's rejection of that static time production, as related to T_a, was premature. But we contend that nonmetric time perception may still be related to T_a, and that such a relationship may be important in resolving the gender differences that have ubiquitously been shown in the T_a literature. This contention is open to empirical resolution.

In general, our findings here, and others cited, support the contention that judgments made by women, for whatever reason, are more conservative or cautious than those of their male counterparts. The underlying reasons for this difference, although perhaps temporal and spatial in nature, await further elucidation. Differences between men and women in T_a work thus far suggest that others that wish to generalize their research to a population, evenly, across gender, of perceiver–actors should consider balancing their designs to reflect this common finding.

Vehicle Type

We found a significant effect for vehicle type, $F(4, 39) = 9.01$, $p < .0001$. Mean-judged T_a accuracy generally declined from motorcycle, compact car, full-size car, and delivery van (Figure 7). Exceptions occurred at $T_a = 1$ s and for juxtapositions between the full-size car and the delivery van. At a traffic-environment level of analysis, this finding is also consistent with the finding that more conspicuous vehicles are seen and smaller ones (e.g., motorcycles) are detected less frequently (Hurt et al., 1981). This ordering also supports the margins-of-safety hypothesis that larger vehicles are given more space–time relative to self-position and a relative vehicle size interpretation. These and other inferences are expanded in the Discussion section. We found a Gender ×

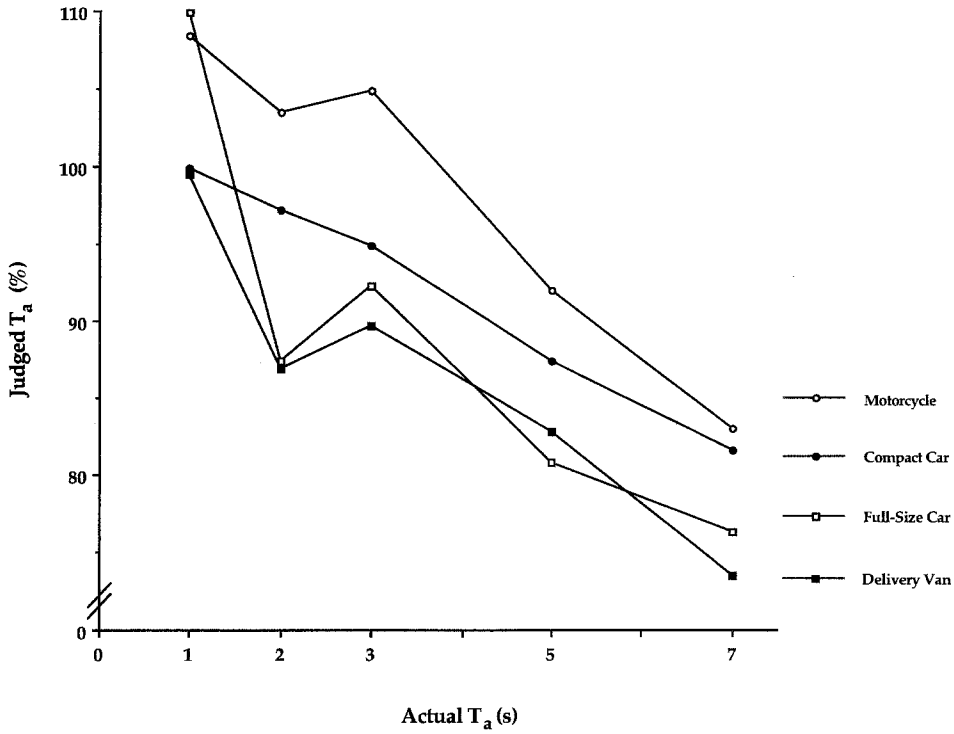

FIGURE 7 Judged T_a as a function of actual T_a for vehicle types.

Vehicle Type interaction to be significant, $F(3, 39) = 9.80$, $p < .0001$. When Tukey HSD procedures were applied to the Gender × Vehicle Type interaction (Figure 8), it was evident that men were more accurate at estimating when motorcycles and delivery vans would reach them than women ($p < .05$), whereas no differences were found for the other two vehicle types.

DISCUSSION

A number of important conclusions can be drawn from the findings. Foremost, participants were more conservative in their T_a estimates as the physical size of the vehicle increased (Figure 1). In our experiment, approaching vehicles were represented as veridically as possible. Hence, the three larger vehicles had rectangular frontal surfaces, whereas the motorcycle had an irregular shape in which vertical extent was preponderant. Both the shape and size may have contributed to the ordering of relative accuracy of judgment with respect to the four vehicle types. If τ was the perceptual basis of T_a estimation, then no

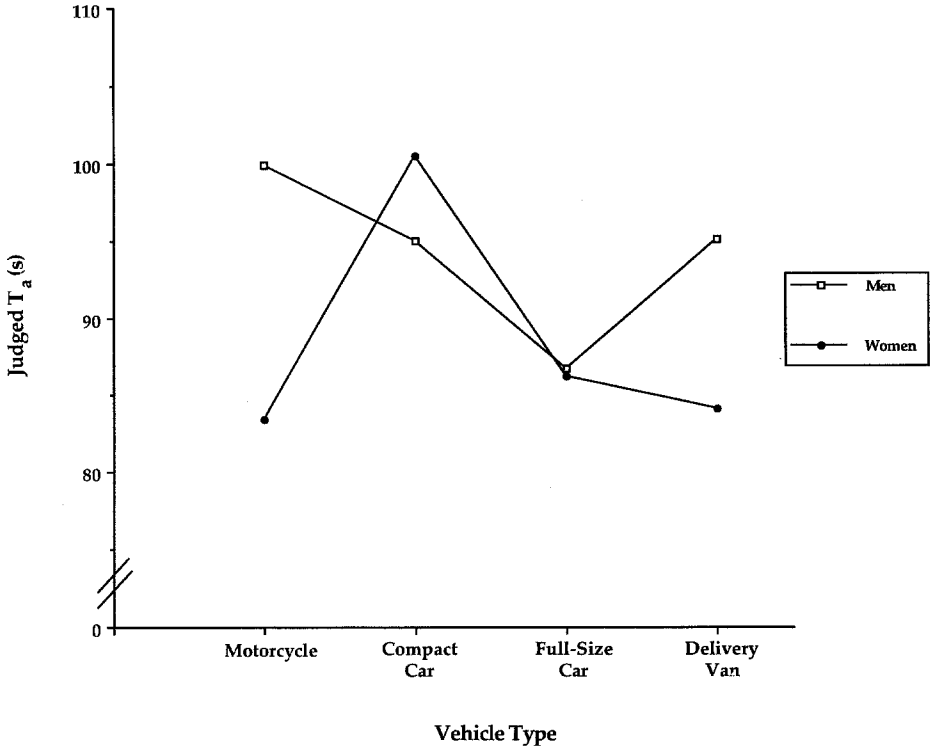

FIGURE 8 Judged T_a as a function of vehicle type for men and women.

differences in T_a estimates for either of the manipulations of vehicle size or removal distance would have been found. However, vehicle size clearly affected the degree of underestimation by observers; larger vehicles produced greater underestimations of actual T_a.

A relative vehicle-size explanation for the pattern of T_a estimates is in accord with DeLucia's (1991a) size-arrival effect (SAE). The SAE, in which object size determines T_a judgments over τ, has been found for relative T_as (DeLucia, 1991a, Experiment 1) and absolute T_a (Experiment 2) in displays of object motion. (The DeLucia experiments used the Todd, 1981, methodology, testing which of the two objects coming towards you will get to you first.) These relative T_a judgments may not reflect the same judgments made in the disappearance methodology. However, using a slightly modified disappearance methodology, Oudejans, Michaels, and de Vries (1993b) found that participants estimated larger squares to be arriving 0.22 s sooner, on average, than smaller squares. They concluded that a size-distance variable needed to be untangled by looking to the real world for answers. These findings were anticipated by Cutting (1986; also cited in Schiff & Oldak, 1990), who wrote: "perceptual systems do their best

in different ways under different circumstances. . . . Perceptual systems may use different sorts of information at different times, even when performing the same apparent task and when all sources equally specify the object or event perceived" (p. 247). The perception of different-size automobiles arriving sooner or later, in a context in which multiple sources of information are available, anticipates the chase for another optical variable.

Participants judged vehicles that had entered the intersection with greater accuracy than vehicles that were removed just before entering the intersection. In either manipulation, the viewing time was held constant. The rate of expansion of an object in the optic array is a function of distance; objects further down the road expand proportionately less than objects about to hit one's car. To assist in the visualization of this relation, Figure 9 shows the differential rates of expansion for two of the vehicle conditions (truck and motorcycle) at the two

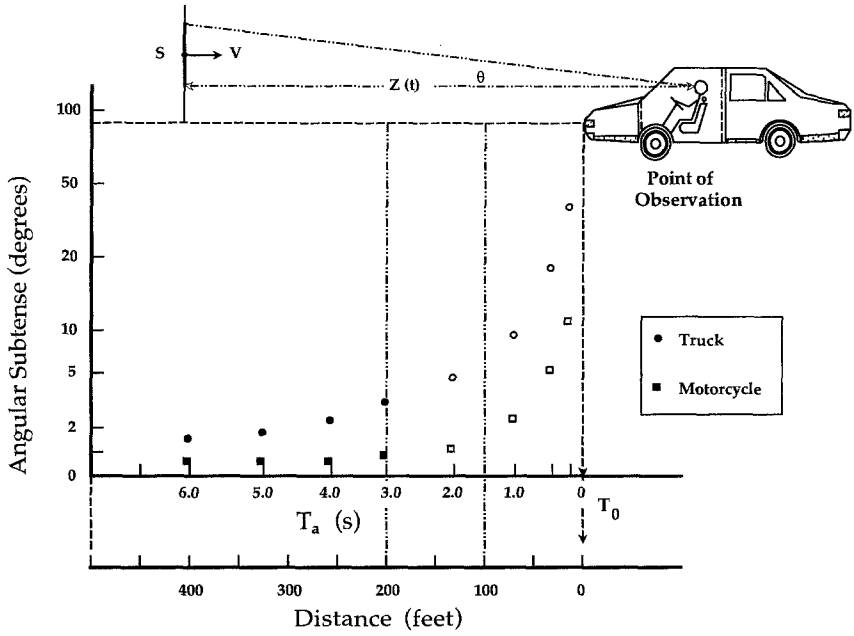

FIGURE 9 Angular subtense by T_a and distance for the truck and motorcycle conditions. Angular subtense was approximated from the start time to the removal distances of 200 feet (60.9 m) and beyond with a constant velocity of 45.3 mph (73 kph). Open circles represent the angular subtense of vehicles that have disappeared from view. T_0 is the arrival time at t = 0. The vehicle at the top of the graph shows the point of observation, S is the height of the object in three-dimensional space, V is velocity of S along the x axis, θ is angular subtense of S in the vertical dimension, and Z (t) is the distance between the point of observation and S. This figure uses data from Bootsma and Peper (1992, Figures 12.1 & 12.2), DeLucia (1989, Appendix 1B), Regan et al. (1992, Figure 2). The drawing is approximately to scale.

manipulations of distance in this experiment. For a constant velocity (V), the angular subtense (θ) of the object (S) increases slowly at further distances (Z[t]) and T_as. As the vehicle T_a decreases, the rate of expansion rapidly increases (see Regan et al., 1992, Equation 1; Bootsma & Peper, 1992, Equation 12.1–12.2). For the conditions shown, the vehicles were removed at 200 feet (60.9 m), just outside the intersection. (The removal distance of 100 feet, used in other trials, is also indicated.) Although the absolute visual angle for the truck was always larger, the size of the visual angle for both vehicles doubled from 6–3 s. Was the change in the visual angle or the inverse of the rate of change of a vehicle image between T_a of 6 and 3 s sufficient to specify the time remaining to contact, that is, what is the minimal level of dilation, or what is necessary for detection? Simpson (1988) found that observers were more sensitive to retinal motion made by approaching objects than for objects that were receding and that practice lowers the discrimination function. Regan and Beverely (1978) identified mechanisms in the visual system that are sensitive to changes in angular size, although their conclusions have been contested (see Simpson, 1988). In addition, Regan and Hamstra (in press) showed that humans are sensitive to changes in τ of about 7% (a just-discriminable difference). Apparently, sufficient viewing time and change in τ were available at the two removal distances, but our results suggest another source of information was used to make judgments.

Results from a simulated driving environment confirmed previous observations that people underestimate T_a (Carel, 1961; Cavallo & Laurent, 1988; McLeod & Ross, 1983; Schiff & Detwiler, 1979; Schiff & Oldak, 1990). Given the near-universal underestimation bias that has been found (see Figure 1), what does this bias afford an observer? In essence, is it better to underestimate the arrival of a survival-threatening vehicle rather than overestimate it. Many researchers (Bower, Broughton, & Moore, 1971; Dunkeld & Bower, 1980; Schiff, 1965; Schiff, Caviness, & Gibson, 1962; Schiff & Oldak, 1990; Yonas et al., 1977; Yonas, Peterson, & Lockman, 1979) have concluded that individuals err in the safer direction of underestimation in order to minimize potential dangers. The robustness of T_a underestimation logically fits this defense-response argument. Results confirmed that observer error is in a safer direction when information is more remote in time and distance and, hence, more uncertain.

Limitations of the "Disappearance" Methodology

Has the "disappearance" methodology reached the logical limit of generalizable utility for real drivers and actual left turns? We proceed by evaluating criticisms and clarifying the limitations of T_a methodology, and we suggest alternative directions for research. First, Bootsma and others have hypothesized that the necessity for action constrains the variability of the action (Bootsma, 1989; Bootsma, Martinuk, & MacKenzie, 1991; Boostma & Peper, 1992; also, see T_a Results section). In our data, and Schiff and Detwiler's (1979) data, a relative

degree of inconsistency was found compared to studies in which action was critical. Drivers do not necessarily have to respond exactly when they make a turn. However, hitting an accelerating ball requires the coordination of action to be precise (Lee et al., 1983). Bootsma's hypothesis, that the accuracy of T_a estimation depends on the intrinsic time constraints of an event, logically fits one boundary within the left turn.[2] The decision to turn left may occur during a time period that precedes T_a (see Figure 9). The arrival of a vehicle at the front-left bumper defines one space–time constraint of an otherwise open time frame if no other vehicles follow the first. However, there is a kind of space–time window constraining a left turn between several oncoming vehicles. A left turn can be performed leisurely or it may require all the capability of the car and driver to execute. Thus, the necessity for action in the left turn varies with the perception of a dynamic affordance or path of safe travel. The perception of an affordance or margin-of-safety may also account for underestimation (Gibson, 1979/1986; Gibson & Crooks, 1938; Hills, 1980; Stoffregen & Riccio, 1990; Yonas et al., 1979).

Do participants in the "disappearance" paradigm take their experimenters literally, that is, do they press the button to indicate they would have acted to avoid an approaching object or did they follow the instructions given by their experimenters? For example, a typical protocol reads, "press a button when [you think] that the object would have reached [you] had it kept coming at the same speed" (Schiff & Detwiler, 1979, p. 651). Stoffregen and Riccio (1990) argued that the pattern of underestimations discussed previously is indicative of when a person would have begun to make a response to avoid the "negative consequences of collision" (p. 270). In the experiments summarized in Figure 1, there were no consequences for failing to avoid an object—it did not jump out of the monitor or projection screen and hit the participant. Similarly, Bootsma and Peper (1992, p. 287) viewed the patterns of underestimation found by Schiff and Oldak (1990) as "displeasing" (i.e., participants should normally react before looming objects get to them anyway). Both of these interpretations imply that the intention to act in a particular way by individuals in these numerous experiments is available for objective study. We find it displeasing that a large set of data has been re-interpreted by "action readers," because it cannot be known whether the participants of these studies responded to avoid the negative consequences of a loom or according to their instructions to wait until a future event. An empirical manipulation of instructions may decide this issue.

Is it necessary to assume that after a vehicle or object has disappeared, some mental process is acting to "carry through" the perception of τ to arrival? For example, Bootsma et al. (1991) suggested that the intervening period of time

[2]Schiff (1993) pointed out that the left turn is not based on "when (exactly) will the oncoming arrive (where I was or T_a), but . . . do I have time/space to get across the road before the oncoming car gets to my projected path of travel (where my car will be)" (p. 3).

between object removal and T_a may involve the postponement of response and underestimations reflect the failure to "fill" the intervening interval with the correct perceptual information. Yakimoff et al. (1993) suggested that this "waiting time" may be filled with "temporal factors related to subjective strategies, decision making, and perceptual motor adjustments" (p. 502). There has also been an appeal for internal representations to provide extrapolation of T_a information (Jagacinski, Johnson, & Miller, 1983; Rosenbaum, 1975). We have labeled this the *filling-in* interpretation. We find that "filling in suggests too much—sometimes a little too much but often much too much" (Dennett, 1992, p. 33). What is the process of filling in? Is it a metric cognitive process (Schiff et al., 1992; also, see Gender section) or some other nonmetric process? Whatever the process is that fills in after the perceptual information is taken away, it seems to demand either some clarification or additional research. Schiff and Oldak (1990) responded to the filling-in argument by citing the differential pattern of their results for judgments of radial (head-on) and tangential (paths not leading to the observer) approaches. Greater underestimation of T_as occurred for the head-on case than in the tangential paths. If participants were filling in, it does not seem reasonable to assume that they would do so differentially for head-on and tangential paths. However, Stoffregen and Riccio (1990, p. 272) suggested that the differential pattern of results reflects a differential necessity to act. In the head-on case, participants have to act; but for tangential paths, they do not have to act to avoid the object. Although this is a plausible inference, it still implies that the intentions of an actor are known.

One shortcoming of the "black-out" paradigm is that it fails to complete the perception–action coupling (Flach, 1990). Usually, cars do not simply vaporize or materialize. Oncoming vehicles are sometimes occluded by other vehicles waiting to turn left at multilane intersections, and this may result in an accident. An interaction between occlusion and local τ provides evidence for this hypothesis. In the laboratory, squares that were partially visible were perceived as arriving later than those that were completely visible (Oudejans et al., 1993a, 1993b), which was predicted by Tresilian's (1991) derivation of two local τs. Ordinarily, drivers actively look to the left, ahead, and to the right for other automobiles before turning left by pressing their foot to the accelerator and turning the steering wheel to continue safely toward their intended destination (Gibson & Crooks, 1938). The simple pressing of a button in these experiments limits the interaction completion of the perception–action coupling to a single action in response to a limited event. Procedures are necessary that will allow a driver to operate a vehicle actively over time while seeking information from signals, signage, roadway, and other moving vehicles. Other lines of research, inspired by Lee (1976), addressed some of these limitations (e.g., Kaiser & Phatak, 1993; Kim, Turvey, & Carello, 1993; Yilmaz & Warren, 1993); they also investigated control strategies based on optical information used at critical times in the driving perception–action cycle (Neisser, 1976).

Future Directions

The perceptual information to turn left appears to be related to: (a) the relative size of the vehicle; (b) the visibility of other vehicles; (c) the relative paths of other vehicles; (d) whether a vehicle is approaching, stopped, or receding from an intersection; (e) the necessity for action by the driver; and (f) whether the driver is in motion or stopped. In our experiment, we attempted to clarify and highlight the perceptual information found in the context of a left turn. However, additional research is required to reduce the loss of life from traffic accidents. The level of research activity on various τs, once confirmed in the laboratory, should be directed to mitigate real-world accidents. Possible applications are discussed next.

Although we examined the perception of an approaching vehicle, applications to drivers moving toward an intersection (egomotion) requires some clarification of previous equivocal results. When persons moved forward, their estimation accuracy of when or whether another vehicle or object might reach them was worse when their peripheral view was restricted (Brown & McFaddon, 1986; Cavallo & Laurent, 1988; Groeger & Brown, 1988). Similarly, when the observation time of approaching objects was manipulated (Groeger & Brown, 1988; Groeger & Cavallo, 1991), the accuracy of estimation decreased. A cognitive interpretation is usually cited when viewing time produces decreases in the accuracy of estimation. Additional processing is inferred to explain this manipulation because perception of invariants from optic flow is hypothesized to be immediate and direct. In contrast, however, manipulations of the length of the viewing time were not significant in studies by McLeod and Ross (1983) in which objects approached observers and by Cavallo and Laurent (1988) in which observers approached objects.

In contrast, DeBari (1991) did not find significant effects for visual field on time-to-contact. The necessity to obtain object information during self-motion over time is not necessarily inconsistent with a τ interpretation. The threshold for detecting fixed objects while moving may simply be raised and require additional time to detect (Probst, 1984, 1986). For example, Simpson (1988) found that when the self is perceived to be traveling forward (egomotion), time-to-contact thresholds are raised. Indeed, Groeger and Cavallo (1991) argued that longer viewing times allowed drivers to stabilize their estimation of speed while approaching an object. In object displays that underwent self-motion (DeLucia, 1991b), SAE was less robust. Because the SAE was extended to individuals jumping over squares of different sizes (DeLucia, 1992), we would expect the relative size of vehicles to affect active driving, as well as passive estimation. In approaching an object while moving, global τ may be implicated because a flow field is present, whereas in the case of being approached by an object, local τ may be implicated (Tresilian, 1990, 1991). Hence, global τ remains to be tested in the context of driving in which a preponderance of information is available.

Another important application of T_a driving research concerns the angle of incidence that other vehicles in the traffic environment travel. Theoretically, objects on a collision course increase in size proportionally and nonlinearly as a function of the distance and time to that object; but when on a tangential path, an object increases disproportionately and nonlinearly (Lee, 1974, 1976, 1980; Peper, Mestre, & Bootsma, 1991; Regan et al., 1992; Tresilian, 1990, 1991). Empirically, many researchers have attempted to test the accuracy of estimation of tangential and head-on vehicles and objects (Groeger & Cavallo, 1991; Kaiser & Mowafy, 1993; Law et al., 1993; Schiff & Oldak, 1990; Todd, 1981). Schiff and Oldak found that as approach trajectories varied from head-on, relative estimation accuracy increased. Groeger, Grande, and Brown (1991) also found slightly more accurate estimates in tangential estimates than in collision conditions. Whether the angle of incidence affects driver T_a estimates, where relative-size information varies, remains to be tested. In addition, it is not known whether the epidemiological evidence or collision incidence from either the right or left at signalized or unsignalized intersections supports the greater observed accuracy for tangential T_a time estimates.

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