Simulator and Field Measures of Driver Age Differences in Left-Turn Gap Judgments

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Research evaluated the effect of varying approach vehicle speed on judgments of the last safe moment to initiate a left turn at an intersection ahead of oncoming traffic. Young (mean age, 33.3 years), young-old (mean age, 65.1 years), and old-old (mean age, 79.4 years) drivers were tested in a controlled field study and in laboratory studies by using varying simulation techniques. A repeated-measures design acquired the same responses from the same subjects by using the same stimuli under all methodologies. Reliable age differences in both target recognition distance and judged minimum safe gap distance were demonstrated, as was an age × speed interaction for gap judgment. Principal findings indicate a relative insensitivity to vehicle approach speed in left-turn situations by older drivers. It is argued that this produces a reliance on instantaneous judgments of perceived distance alone, disproportionately increasing the risk for older drivers when there is an isolated speeder in the opposing traffic stream. A countermeasure need is thus identified, but countermeasure effectiveness was not investigated in the present research. Furthermore, the present findings suggest that image and scene attributes including high resolution and correct size and perspective cues may be prerequisites for valid and generalizable driving simulation measures of visual sensory and perceptual task performance.

This paper reports on age-related differences in driver performance when individuals must judge the last safe moment to proceed with a left turn ahead of oncoming traffic. The findings of this investigation may be applied directly to the development of engineering countermeasures to reduce intersection traffic maneuver problems of this type. To this end key task demands of the left-turning situation, visual information-processing aspects of gap judgment, and relevant driver performance differences are first reviewed. Laboratory and controlled field experiments are then reported. These document the effects on gap judgment of driver age, vehicle approach speed, and various stimulus image characteristics associated with alternative simulation techniques.

Left-turn traffic maneuvers appear to create special problems for older drivers, as evidenced both by their overinvolvement in this accident category and by self-reports from older road users; furthermore, the specific reason cited most frequently for the involvements of older drivers in accidents in left-turn situations is failure to yield (*1,2*). Assuming that an oncoming vehicle has been detected by a driver waiting to turn left, two broad areas of concern for safe performance in this situation are the driver's understanding of his or her right-of-way status as conveyed by traffic control devices at the intersection and motion perception outcomes that yield appropriate gap judgments for the initiation of turning movements. Parallel research describing a cognitive engineering approach to improve left-turn signal displays has recently been documented (*3*).

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The present study addresses the sensitivity of gap judgments to driver age and task variables and the importance of such relationships to accident risk reduction for older drivers.

Prior investigations have addressed motion perception abilities pertinent to driving, including time-to-collision (TTC) and gap-acceptance judgments, although only a subset has compared older and younger subjects. In TTC estimates drivers estimate how long it takes, moving at a constant speed, to reach specified points in their paths. They are hypothesized to be based either on an optic-flow process, in which the driver's analysis of the relative expansion rate of an image (such as an oncoming vehicle) over time provides the estimate of TTC directly (*4–6*), or on a cognitive process in which TTC is estimated by using speed and distance information. In the first case the driver relies on two-dimensional information, that is, angular separation cues (the image gets larger), to estimate TTC; in the second case the driver calculates TTC on the basis of three-dimensional information. As reported later, a decline (possibly exponential) in the ability of older subjects to detect angular movement compared with that of young subjects can be described. By using a simulated change in the separation of taillights, indicating the overtaking of a vehicle, threshold elevations of greater than 100 percent were shown for drivers 70 to 75 years old compared with those for drivers 20 to 29 years old for brief exposures at night (*7*). Older persons may in fact require twice the rate of movement to perceive that an object's motion-in-depth is approaching, given a brief (2.0-sec) duration of exposure. Also, research has indicated that relative to younger subjects, older subjects underestimate approaching vehicle speeds, with greater errors of underestimation at higher speeds (*8*). Furthermore, a prior analysis of judgments of the last possible safe moment to cross in front of an oncoming vehicle traveling at lower speeds versus that for one traveling at higher speeds has shown that older persons allowed the shortest time margins at a 96-km/hr (60-mph) approach speed; in fact, older persons accepted a gap to cross at an average constant distance of slightly less than 152.4 m (500 ft), whereas younger subjects allowed a constant time gap and, thus, increased distance at higher versus lower speeds (*9*).

The present investigation sought to replicate the finding of relative insensitivity to vehicle approach speed for older drivers in the left-turn situation, specifically, by using alternative stimulus display techniques in a laboratory simulator, and then to apply a repeated-measures design to validate the gap judgments of the same test sample under controlled field conditions.

SUMMARY OF EXPERIMENTS

A laboratory experiment presented a young to middle-aged and two older driver groups with a single oncoming (target) vehicle

approaching at low and high speeds by using alternative displays to show the opposing leg of the intersection where the subject was waiting to make a left turn across traffic. Separate blocks of trials used a 20-in. television monitor, a large-screen video projection image, and a large-screen cinematic (35-mm) image to display the filmed approach of an identical target vehicle at the same location. All subjects viewed all target approaches by using all display techniques. In each trial subjects first performed a target recognition response when they could identify the approaching vehicle in the distance across the intersection; then, later during the target vehicle's approach, they indicated their judgment of the last safe moment to proceed with a left turn, yielding distance measures for each dependent variable.

In a following controlled field experiment, the same test sample watched opposing (target) vehicle approaches at the same speeds while sitting behind the wheel in an instrumented vehicle positioned so as to provide the same view across the same intersection as shown previously in the laboratory driving simulator. The same target vehicle filmed earlier for the laboratory stimulus preparation was used in the field trials. Again, subjects made responses of the last safe moment to proceed at the instant during the target's approach when they judged that it had become unsafe to initiate a left turn in front of the oncoming vehicle.

METHODOLOGY

Laboratory Experiment

Subjects

A total of 79 paid test subjects in three age groups (25 young/middle-aged, 29 young-old, and 25 old-old drivers) were recruited for this research through face-to-face, one-on-one solicitations at Pennsylvania photo license centers, where a person's birth date (month of year) is the determining factor as to who appears on any given day. The quasi-random sample obtained in this manner has been shown to provide a more representative range of visual capabilities in older age cohorts relative to those in samples obtained through newspaper advertisements or appeals to large groups of older persons (*10*). The mean age of the subjects in the young/middle-aged group was 33.3 years (range, 20 to 53 years), the mean age in the young-old group was 65.1 years (range, 56 to 72 years), and the mean age in the old-old group was 79.4 years (range, 75 to 91 years). Each age group included approximately 60 percent males and 40 percent females.

A study sample falling within age norms for visual and cognitive performance was defined by using a preliminary test battery: static acuity (corrected), contrast sensitivity, stereo depth perception, forward and reverse digit span, and understanding of spatial relationships indicated by performance on the WAIS-R block design subtest. No evidence of visual pathology or cognitive dysfunction sufficient to excuse any of the sample recruits from participation in this research was found.

Stimulus Materials

The test stimuli for the television, video projection, and cinematic trial blocks were produced from the filmed (30 frames/sec) approach of a white Mercury Marquis sedan on a two-lane highway at a speed of 48 km/hr (30 mph) from the perspective of a driver waiting to turn left onto an intersecting roadway. The approach of the target vehicle began out of sight behind a curve approximately 1.6 km (1 mi) from the camera position; an on-board distance-monitoring computer recorded the target vehicle's position every 1/30 sec during its approach, generating a look-up file of its separation distance from the subject (camera position) for every frame. All stimuli were recorded on 35-mm film stock by using a Panavision camera equipped with a 30-mm anamorphic lens. This lens provided a distortion-free field of view of approximately 72 degrees at an effective focal length of 1.5 cm (0.59 in.). A film-to-tape transfer was performed to produce the video master, which subsequently was stored on laser disc for stimulus presentation.

By using the display apparatus as described later, various image characteristics were presented to subjects in each block of trials in the laboratory. The video images were National Television Standards Committee (NTSC) quality; although this format theoretically permits 525 horizontal lines of resolution, postproduction and transfer to laser disc resulted in an effective resolution of only 300 to 350 scan lines. The 35-mm cinematic format, by comparison, displayed an image resolution of more than 3,000 lines. The large-screen display formats preserved correct size and perspective cues, such that the angular change associated with the target's motion in depth provided the same cues available to a driver viewing the scene through the windshield. The 20-in. television monitor display compressed the target stimulus, however, and did not present absolute changes in the angular size of the target that were accurate for its motion in depth as viewed under real-world conditions. Thus, the television monitor trials presented relatively lower resolution images, without correct size and perspective information; the projection video trials presented correct size and perspective information, also at lower resolution; and the cinematic trials presented correct size and perspective information at extremely high resolution.

The visual background of the stimulus scene was an uncluttered rural environment, and the target vehicle was the only vehicle visible in the scene. The luminance of the stimulus scenes in all display types exceeded 100 cd/m^2, as measured with a Pritchard 1980A photometer.

Apparatus

A driving simulator consisting of a Fiat 128 body and frame (with engine and gas tank removed) was used for the large-screen display trial blocks. A single-seat driving buck consisting of a frame without external body panels was used for the television monitor trials. In both data collection systems, a steering wheel-mounted response button was used to obtain target recognition responses, and a switch activated by brake pedal depression was used to record last safe moment to proceed responses.

A Stewart Lumiflex 180 rear-projection screen was used for the video projection and cinematic trials. The screen horizontal dimension was 274 cm (108 in.), and the viewing distance from the subject's eyes to the screen was 188 cm (74 in.). The viewing distance for the 20-in. (Sony) television monitor trials was 61 cm (24 in.). A Pioneer LD-V8000 laser disc player was used for all video trials. For the large-screen video trials a Barcodata 1001 projector was used, with additional signal enhancement provided by an Ikegami DSC-1O5OS digital scan converter. A 35-mm projector with an anamorphic lens was used to display the stimuli for the cinematic trials. A Society of Motion Picture and Television Engineers time

code reader was used with the 35-mm projector to identify individual frames of film corresponding to a subject's button-push and brake pedal depression responses in the laboratory.

A 386/50 personal computer (PC) was used to control the presentation order of test stimuli, to initiate the displays of video stimuli, to record the times of the button-push and brake pedal depression responses, and for the video trials, to control the apparent speed of the target vehicle's approach. Since the target approach was filmed at 48 km/hr (30 mph), a PC command to double the playback speed for the laser disc was used to produce a 96-km/hr (60-mph) approach. The high-speed approach with cinematic stimuli was achieved through studio production of a copy of the stimulus film with every other frame removed.

Procedure

Data collection was conducted for one subject at a time in two successive visits to the laboratory. During the initial visit the visual and cognitive screening measures were obtained, and the subject performed the dependent measures by using the large-screen projection video display. During the following visit the television monitor and cinematic trials were performed. Trial order by target approach speed (48 and 96 km/hr) was counterbalanced within blocks for each age group, but all subjects performed the video projection trials first and then the cinematic trials and the television monitor trials. Unfortunately, the expense and limited availability of the 35-mm projection equipment precluded the complete counterbalancing of trials, that is, by display methodology, in the laboratory. At least 1 month elapsed between visits to the laboratory, however, reducing any possibility that learning from the large-screen video trials could have contaminated the cinematic data collection protocol.

After a subject was seated in the simulator and seat adjustments for his or her comfort were completed, a simple reaction time (RT) task was administered by using a button-push response to a light-emitting diode mounted on the dashboard and presented with random delay over seven trials. The quickest and slowest responses were discarded, and the mean of the remaining five trials was recorded as the simple RT or movement time for the subject. This was done to permit a correction for individual differences in RTs when calculating the recognition and gap judgment distances for each test condition, since movement time differences per se (i.e., independent of the information-processing operations underlying gap judgments for approaching vehicles) were not of direct interest in the study.

At the beginning of each trial the experimenter paused the first frame of the stimulus scene to deliver instructions. The target vehicle was not yet visible in the distance in this scene. The experimenter pointed out relevant scene elements to reiterate the scenario of a driver waiting to turn left onto the intersecting roadway and then reminded the subject that two responses were required: (a) press the button on the steering wheel at the earliest moment that you can identify the target vehicle approaching in the distance, and (b) depress the brake pedal at the last possible safe moment to turn in front of the target vehicle. The brake pedal response, although not typically associated with the initiation of a turn, nevertheless yielded cleaner data during pilot testing than, for example, a steering wheel movement in which the precise degree of deflection required to register a response was more ambiguous. None of the subjects evidenced any confusion or difficulty in understanding or performing the brake pedal response.

Controlled Field Experiment

Subjects

The test sample for the field experiment was retained from individuals participating in the prior laboratory testing. Individuals in the same age groups were sampled. Actual sample sizes within each age group in the field study are indicated in the data summary presented later in this section in Table 1.

Stimulus Materials

The same white Mercury Marquis sedan used during filming of the test stimuli for the laboratory study served as the target stimulus for the controlled field experiment. It was driven by a confederate who was in radio contact with the experimenter in the subject vehicle.

Apparatus

The subject vehicle was instrumented with hardware and software systems to monitor the distance traversed from a known reference point by the target vehicle on each trial and to record the subject's gap judgment response when the target reached the last possible safe moment for the subject to turn in front of it. A hand-held response button was used by each subject to perform the gap judgment dependent measure.

A microprocessor linked to the transmission in the target vehicle monitored the distance traveled from its (constant) starting point in each trial. This measurement system was accurate to the nearest 0.3 m (1 ft). The subject vehicle was equipped with a transmitter, activated by the hand-held button-push mechanism, that notified the distance-monitoring computer in the target vehicle the instant that the subject pushed the button to indicate his or her last safe moment response. This signal froze the display of the traversed distance, permitting calculation of target separation distance at the time of response by subtraction from its known distance [slightly under 1.6 km (1 mi)] at the starting point.

Procedure

Subjects were brought by van to the field data collection site, on NJ-29 in Hunterdon County, at the identical location where the laboratory test stimuli had previously been filmed. Traffic on this highway, although light during the data collection period of 10:00 a.m. to 3:00 p.m., was not controlled; therefore, the subject sat in the passenger seat position in the instrumented vehicle and the experimenter occupied the driver's position, to move out of the way of traffic if necessary. This protocol allowed subjects to attend solely to the approach of the target vehicle. Any interrupted trials were repeated.

Once the experimenter had positioned the instrumented vehicle properly at the intersection, she radioed the confederate in the target vehicle when to begin the approach. However, since this site was located on an open roadway, extraneous vehicles periodically entered the opposing lane between the subject and the target position or overtook the target vehicle at high speed from the rear. Data collection was aborted whenever this occurred, but some confusion was possible at the beginning of any given trial as to whether a just-detectable vehicle in the distance was in fact the target. Therefore,

TABLE 1 Mean (M) and Standard Deviation (SD) Distances in Meters for Each Age Group for Each Dependent Measure Under Each Experimental Methodology

	Experimental Methodology																							
	Laboratory: Television Monitor Display						Laboratory: Projection Video Display						Laboratory: Cinematic Display						Field: Instrumented Vehicle					
Age Group	Target Speed: Low			Target Speed: High			Target Speed: Low			Target Speed: High			Target Speed: Low			Target Speed: High			Target Speed: Low			Target Speed: High		
	Target Recognition Distance (m)																							
	n	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD						
Young/middle-aged	22	263	42	22	229	47	25	296	46	25	248	55	23	338	17	23	341	28						
Young-old	26	271	51	26	232	50	28	297	57	28	261	68	25	320	37	24	336	20						
Old-old	21	266	24	21	217	57	24	304	43	23	259	56	20	310	32	21	319	28						
	"Least Safe Gap" Distance (m)																							
	n	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD	*n*	M	SD
Young/middle-aged	22	95	34	22	100	29	25	146	55	25	148	46	23	163	52	23	201	50	12	100	49	11	132	52
Young-old	26	137	56	26	124	42	28	228	67	28	192	68	25	203	67	25	230	56	13	156	50	11	158	33
Old-old	21	137	55	21	119	40	24	253	48	24	222	58	21	216	72	21	229	62	14	166	62	15	161	53

1m=3.28ft

contrary to the laboratory methodology, the experimenter verbally cued the subject to the presence of the target vehicle as it became visible as a point source in the distance, and no target recognition distance data were obtained in the controlled field experiment. After the subject pressed the hand-held response button to perform the dependent measure, the experimenter waited for the target vehicle to pass by and then pulled off the road onto the shoulder while the confederate repositioned the target vehicle at its starting point if another trial was to be performed.

RESULTS

The data from the laboratory and field experiments are summarized in Table 1. Table 1 shows the means and standard deviation for the recognition distance and gap distance measures for each age group as a function of target approach speed and the number of subjects completing data collection under each test condition. In addition, target recognition and gap distance data are provided in Figures 1 and 2, respectively, for each methodology. As noted earlier no recognition distance data were obtained in the controlled field trials. Statistical tests of the main effects and interactions for the age group and target speed variables on each dependent measure were performed by using the General Linear Models Procedure (PROC GLM) in SAS, with program options for repeated-measures designs within each block of trials corresponding to a single experimental methodology.

A significant effect of age group on the judged minimum safe gap was demonstrated by all laboratory test methodologies such that increasing subject age resulted in larger gap requirements. The same trend was observed in the controlled field data, but it failed to reach significance. The magnitude of the age group effects was given by $F = 20.66$ [degrees of freedom (df) = 2; $P < .0001$] by the video projection methodology, $F = 4.48$ (df = 2; $P < .01$) by the television monitor methodology, and $F = 3.21$ (df = 2; $P < .05$) when the target stimulus was presented cinematically. In addition, the effects of age group on target recognition distance were demonstrated by using the 35-mm film stimulus display methodology, because younger subjects recognized the target vehicle at significantly greater distances than older subjects ($F = 6.04$; df = 2; $P < .004$). No reliable effect of age group on this dependent measure was found for the video projection or television monitor methodologies, and target recognition distance was not measured in the controlled field trials.

Differences in target approach speed resulted in significant differences in both target recognition distance and the judged minimum safe gap for all laboratory methodologies. Overall, increasing target speed led to significantly shorter minimum safe gap judgments ($F = 9.57$; df = 3; $P < .0001$) as well as shorter target recognition distances ($F = 51.51$; df = 3; $P < .0001$) by using video projection to present the test stimuli. For the television monitor data the same pattern was observed: decreasing minimum safe gap judgments ($F = 5.63$; df = 1; $P < .02$) and shorter target recognition distances ($F = 71.83$; df = 1; $P < .0001$) with increasing target approach speed. With cinematic stimulus presentation, however, just the opposite results were demonstrated, that is, significant increases in the judged minimum safe gap ($F = 31.55$; df = 1; $P < .0001$) and target recognition distance ($F = 5.25$; df = 1; $P < .03$) as target speed increased. In the field trials only the gap judgment measure was obtained; for these data an increase in the judged minimum safe gap with increasing target approach speed ($F = 14.28$;

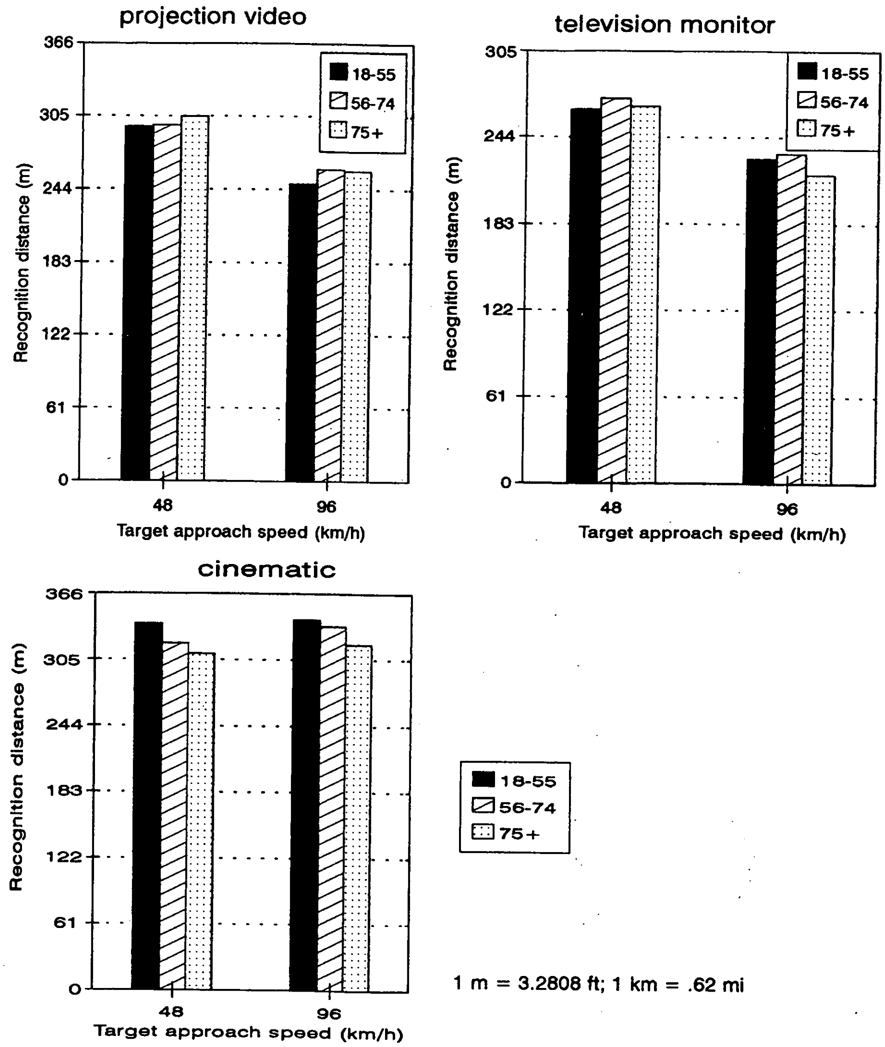


FIGURE 1 Target recognition distance as function of approach speed for three driver age groups for projection video, television monitor, and cinematic stimulus presentation methodologies.

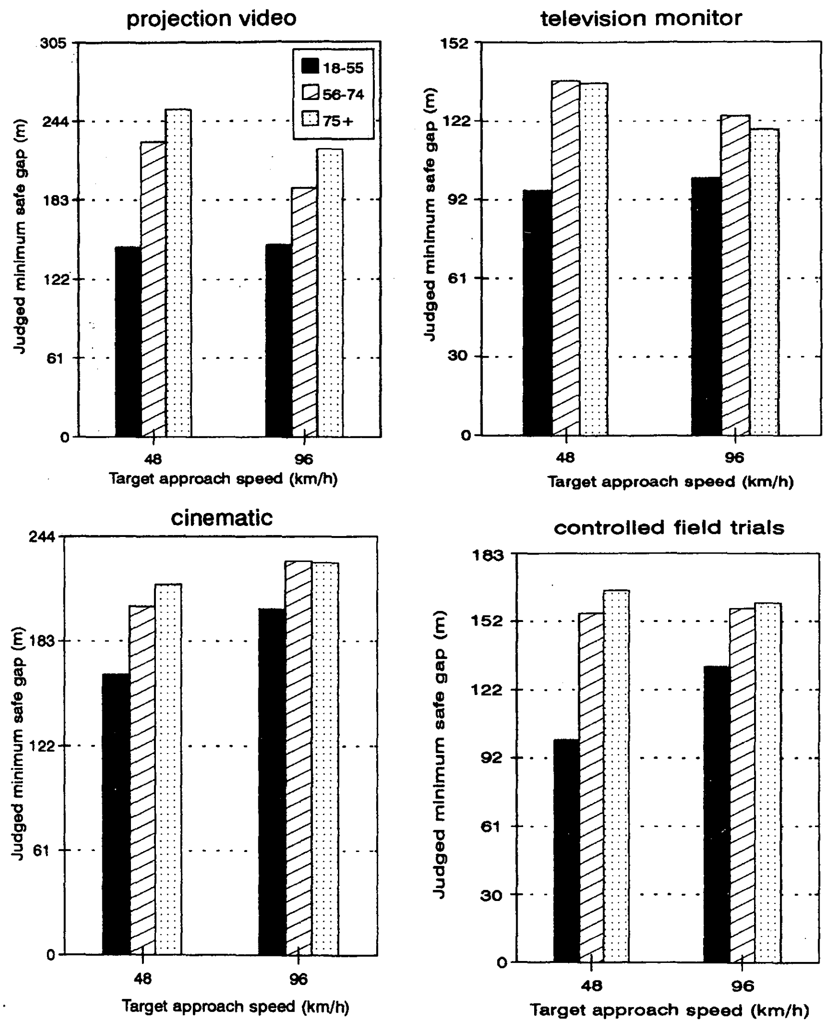
df = 1; $P < .0009$) mimicked the trend observed in the cinematic data in the laboratory.

Most interesting were significant interaction effects on gap judgment involving subject age group and target approach speed, which were demonstrated for the video projection and television monitor methodologies in the laboratory and for the controlled field trials. By using video projection to present test stimuli the interaction effect was demonstrated because the judged minimum safe gap for young/middle-aged drivers remained relatively constant across target speeds, whereas both the young-old and old-old drivers accepted smaller gaps as target speed increased ($F = 4.95$; df = 6; $P < .0001$). This identical pattern was also found in the television monitor data ($F = 3.14$; df = 2; $P < .05$). The results of the controlled field trials, however, differed markedly: the judged minimum safe gap of young/middle-aged drivers increased along with target speed, whereas the responses of young-old and old-old drivers were insensitive to this independent variable ($F = 4.49$; df = 2; $P < .02$). For the cinematic laboratory data, the pattern of differences paralleled that observed in the field, but at $P < .09$ it failed to reach significance.

GENERAL DISCUSSION OF RESULTS

The primary research hypothesis, that older drivers would experience a relative insensitivity to vehicle approach speed in left-turn situations, was reliably demonstrated in controlled field trials and was underscored by a consistent pattern of results by using cinematic stimuli in the laboratory. Under these test conditions, as one would hope, increasing conflict vehicle speed caused young drivers to increase their judgments of the minimum safe gap to initiate a turn while waiting at an intersection for oncoming traffic to clear. Older driver gap judgment distances, however, did not change significantly for a 48-km/hr (30-mph) versus a 96-km/hr (60-mph) target approach speed.

Not only did the proportional change in gap judgment from one target speed to another differ markedly as a function of driver age, but it also differed as a function of the method of stimulus presentation. Although significant interactions between age and target speed were demonstrated in the video projection and television monitor laboratory trials, these data were characterized by unchanging gap judgments across speed by younger subjects and by



1 m = 3.2808 ft; 1 km = .62 mi

FIGURE 2 Gap distance judgments as function of approach speed for three driver age groups for projection video, television monitor, and cinematic stimulus presentation methodologies.

substantial decreases in minimum safe gap size judgments by older subjects for faster target approaches.

The study's findings thus merit discussion in two important contexts: the design of engineering countermeasures to improve the safety of older drivers in performing left turns at intersections and the validity of simulator measurements of driver perceptual and cognitive responses by using various display techniques.

Two complementary countermeasure strategies have the highest potential to ameliorate older driver problems in turning situations: (a) cue the older (turning) driver to the presence of vehicles approaching at significantly higher-than-expected speeds (i.e., those that exceed the posted limit by a fixed amount) and (b) and slow down through traffic and make through drivers more aware of the potential for a conflict ahead with a turning vehicle. Potential means for achieving these behavioral goals include speed-actuated active warning devices for turning drivers, rumble strips for through traffic on intersection approaches, and special permissive phase signal treatments that may induce greater caution among turning drivers (e.g., flashing yellow or flashing red instead of the steady green ball now most widely used as the permissive phase treatment).

Somewhat less apparent is the extent to which the simulation techniques used in this research imposed limitations on the abilities of drivers of different ages to process motion cues to extract information about the speed-distance relationships of other vehicles. Since it must be assumed that display artifacts were absent from the controlled field data, the observed pattern of responses for younger and older drivers can be interpreted as reflecting a diminished capability of older subjects to process motion cues under conditions in which there is no deficiency of information in the image. When a deficiency of spatial information exists it might be expected to also result in distortions in the judgments of younger subjects. Specifically, the loss of high-frequency spatial cues might be expected to level performance across age groups, because (younger) subjects with the capability of using such information do not have it available to them.

The similarities of response patterns in the cinematic data to those in the field data suggest that the film methodology provided suffi-

cient information for valid gap judgments, whereas differences associated with the video projection and television monitor data indicate one or more deficiencies in the information provided by these stimulus presentation methods. The key differences in the attributes of each display type are a loss of realistic target size and perspective cues with the NTSC signal of the television monitor, a loss of image resolution (high spatial frequency information) but preservation of correct perspective with video projection, and realistic size and perspective cues plus a high image resolution with the 35-mm cinematic stimuli.

The smaller minimum safe gap judgments of the older subjects by the video projection and television methodologies but not the cinematic methodology may reflect a floor effect in spatial information-processing capability for a degraded (low-resolution) image. Logically, more processing effort will be required to reach a confident judgment regarding target size when viewing a diffuse image versus a sharply defined image. The instantaneous processing of size cues for a diffuse target should therefore be interfered with to a greater extent by increasing target speed, and for observers with diminished motion perception capabilities, a minimum sampling interval may also be reached. This increased processing difficulty alleged to occur at higher speeds could produce a lower target recognition distance for degraded images, and the minimum sampling interval, the suggested information-processing floor effect, would correspondingly result in a lower gap judgment distance at 96 than at 48 km/hr. Although the target recognition distance also was reduced for the young/middle-aged subjects by using the video projection and television monitor displays, their hypothesized greater efficiencies in spatial information processing could have compensated to a degree for this limitation in the availability of relevant spatial cues.

With the cinematic display target recognition distance did not decrease for any age group for the lower versus the higher target approach speed. Thus, in the absence of significant image degradation, the spatial information that drivers seek for gap judgments was available at a distance sufficiently beyond the perceived minimum safe gap that afforded an adequate processing time to all subjects for the cognitive operations underlying speed or distance estimation; that is, no floor effect of the sort suggested earlier occurred. Under these circumstances it makes sense that the observed differences in the mean response magnitudes for gap judgments between groups can be accounted for strictly in terms of individual (group)-related diminished capabilities, as opposed to stimulus-bound factors.

An alternative interpretation of the present findings deserves comment. There is some appeal to couch the results of subjects' gap judgments in this research in terms of TTC values instead of target separation distances. Of course, it is individuals' perceived TTC that dictates their go–no go responses in this driving situation. Earlier research has demonstrated that there is a general underestimation of TTC such that as absolute TTC increases, error in judging TTC also increases (*11*). More critical is an understanding that perceived TTC is a derived construct: it depends on a prior perception of approaching target speed. Any interpretation of the present findings within a TTC framework must take this contingent relationship, as well as the perceptual distortion noted earlier, into account.

In conclusion, achieving valid measures of age differences in vehicle motion perception and associated maneuver decisions by using laboratory driving simulation techniques appears contingent on the highest possible realism in presenting the driving situation to which the results are to be generalized. At a minimum to understand the relationships between driver age and operational factors such as the driver's estimate of the speed of an oncoming vehicle, the preservation of a high image resolution plus the use of correct size and perspective cues appear to offer clear advantages in driving simulation research.

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