Understanding Driver Behavior Through Application of Advanced Technological Systems

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The use of the unecological removal research scenario in recent years has been forced because of technological limitations. However, with the advent of three-dimensional modeling programs and high-fidelity graphic systems, the ability to accurately represent real-world situations in computer-generated worlds has become easier, cheaper, and more realistic. A time-to-contact (TTC) experiment is reported in which the manner of removing an approaching vehicle from the environment was manipulated. One scenario, the disappearance condition, featured a traditional, instantaneous removal of a vehicle. The purpose of this research was to determine if a more ecological research scenario, one in which the approaching vehicle becomes occluded by a naturally occurring object (the occlusion condition), influences a driver's ability to estimate TTC accurately. The available visual information was essentially equivalent in both scenarios. If the level of ecological validity has no effect on estimates of TTC, estimates of TTC between the two scenarios would be expected to be similar. Results, however, showed estimates with 14 percent greater accuracy in the occlusion condition compared with the disappearance condition, implying that researchers have been using a research scenario that biases estimates of TTC. Further, the results of the present findings imply that there are processes that occur in real world settings that have not being accounted for in previous TTC research.

In 1993, the monetary cost of injuries and deaths due to motor vehicle accidents was $167.3 billion dollars in the United States (*1*). This cost is secondary to the personal cost of these accidents. Specifically, in the same year 2,000,000 people experienced disabling injuries and 42,000 persons lost their lives as a direct result of motor vehicle accidents (*1*). It is because there are such great loss of life and disabling injuries that there is a need to understand the factors that contribute to accidental collisions. With this information steps can be taken by transportation engineers and planners to reduce both the personal and monetary cost of accidental collisions.

Researchers have begun to determine what factors, both internal and external to the driver, contribute to accidents and how these factors affect a driver's ability to deal effectively with and to avoid accidents. One such factor is the ability to determine when an object will reach a person's position in space. This ability has been commonly termed time to contact (TTC) (*2–4*). The ability to determine TTC is a fundamental and critical skill needed to survive in any environment, but it is especially critical in a land transportation environment. For example, when a driver is stopped at an intersection and is attempting to cross a road, he must first determine when other vehicles will reach his position in space. With this information the driver can then coordinate his activities to cross the intersection successfully. Failure to perform this task successfully may be a prelude to accidental collision resulting in injury or death.

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Results of research investigating TTC issues has indicated several factors that influence estimates of TTC. A few of the internal factors include the age and the sex of the driver. Schiff et al. (*5*) found significant differences between estimates of TTC by younger and older experiment participants, and, Hoffmann and Mortimer (*6*) indicated that very young participants and older participants used different methods for determining TTC. Research has indicated that men's estimates of TTC are more accurate than women's estimates and that men's estimates are less variable than women's (*3,7,8*). In addition to these findings, it appears that sex and vehicle approach velocity may be interactive factors. In particular, Schiff et al. (*5*) found no differences between the sexes when using a small range of vehicle approach velocities, whereas when using a wider range of vehicle approach velocities, significant differences were found (*3,7,8*).

Some of the external factors that influence estimates of TTC include the velocity of the approaching vehicle, the total viewing time of the approaching vehicle, and the total viewing distance of the approaching vehicle. With increases in vehicle approach velocity (*3,5,7,9*), viewing time (*7,8,10*), and increases in viewing distance (*3*), the accuracy of TTC estimates increases. Findings of previous research have also indicated that participants consistently underestimate TTC as actual TTC increases (*3,5–8,10–13*). In addition, Manser and Hancock (*3*) and Schiff and Oldak (*8*) indicate that large individual differences exist in the ability to estimate TTC.

The ability to determine TTC has been examined through the use of a removal research scenario, in which a vehicle is approaching a participant on a collision course and at some point during the approach the vehicle is removed (disappears) instantaneously from the visual environment or the entire scene becomes blank. The driver's task is then to respond when he believes that the approaching vehicle would have reached his position had it not been removed from the scene. It is easy to relate this research scenario to a real-world traffic situation in which a driver is waiting to make a left turn at a four-way intersection and his view of an approaching vehicle to the left or right is temporarily obstructed by shrubbery or a parked vehicle on the edge of the road. In this situation the visual information specifying when the approaching vehicle will reach the driver's position in space is present for a limited amount of time while the vehicle is visible and before it becomes occluded.

Researchers have used a variety of methods to create the removal research scenario. One of the earliest and most popular methods entails filming an approaching vehicle and then reverse-editing the film so that the vehicle is removed from the scene or the entire scene becomes blank at the desired time or location (*5,8*). In allied research examining time-to-arrival skills, researchers have produced the removal scenario by having a driver sit in the passenger seat of a moving vehicle and wear a head-mounted apparatus. At some

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point during the driver's approach to an object, a visor on the head-mounted apparatus drops down and instantly occludes the driver's view (*14*). Another method for creating the removal research scenario involves the use of computer-generated graphics in driving simulators (*3,7*). Similar to the filmed vehicle approach, the computer-generated scenario depicts a vehicle approaching a driver on a collision course. At some point during the vehicle's approach it is removed from the computer-generated scene.

Although the removal research scenario is similar to real-world situations, it is easy to see that the two are not identical. In particular, vehicles do not instantaneously disappear from the driver's view. In real-world driving scenarios, vehicles become occluded by objects in the environment, including the previously mentioned shrubs and parked cars. It is ironic, then, that in an attempt to replicate real-world driving scenarios on film and by computer generation, researchers have created a research scenario that is highly unecological. One of the underlying reasons for the use of the removal research scenario is the previous limitations in technology. However, with the advanced computer systems available currently, the ability to replicate real-world scenarios in a more realistic manner can be accomplished with greater ease and less expense. In particular, with the advent of three-dimensional environmental modeling, the ability to depict dimensions and depth has been enhanced greatly. This ability allows researchers to ask research questions in a more ecologically valid manner. With regard to the current research, the driver can now see the approaching vehicle becoming occluded by a naturally occurring object. This new capability forces researchers to step back and examine the method used to study the factors that influence the ability to estimate TTC. Does this ability depend on the type of research scenario presented to drivers?

The purpose of the current research was to determine if the type of research scenario presented to drivers affects the ability to estimate TTC. Drivers were presented with two research scenarios. The first research scenario indicated to the driver that a vehicle was approaching on a collision course. At some point during the vehicle's approach, it was removed from the scene instantaneously. This traditional removal research scenario was contrasted with a more ecologically valid occlusion research scenario in which the approaching vehicle become occluded by a shrub on the side of the road. The effects of driver age, driver sex, and vehicle approach velocity on estimates of TTC were also examined. The following hypotheses were formulated:

1. Estimates of TTC will be more accurate for the occlusion research scenario because of the availability of alternate sources of information which is normally available in more ecologically valid scenarios.
2. Estimates of TTC will be more accurate when the vehicle approaches the driver at higher velocities.
3. In alignment with previous research, men's estimates of TTC will be more accurate than women's.
4. Younger and older drivers will estimate TTC differently.

EXPERIMENTAL METHOD

Experiment Participants

Participants in this experiment were 10 men and 10 women between 18 and 30 years of age and 10 men and 10 women between the ages of 55 and 70 ($n = 40$). Participants were recruited from faculty, staff, and the student body at the University of Minnesota and from local churches, retirement communities, and Minneapolis senior citizen organizations. All participants possessed a valid Minnesota or Wisconsin driver's license, had 20/20 vision or vision corrected to 20/20 via contact lenses or glasses, and possessed no apparent physical or cognitive limitations that would have affected performance in this experiment.

Experimental Apparatus

The apparatus used was a high-fidelity wrap-around environment simulator (WES) consisting of a steel and wood infrastructure onto which eight white fiberglass screens were affixed. Each screen was 243 cm high and extended up from the floor. Each screen was synthesized with the adjacent screens so it appeared as if there was one single screen wrapping 360 degrees around the driver and vehicle. At the widest point the screens had a diameter of 548 cm, and the diameter at floor level was 472 cm. The driving scene presented to participants was created by Coryphaeus Easy Scene computer software, generated by a Silicon Graphics, Incorporated, Onyx computer and projected through three Electrohome ECP-3100 projectors onto the WES. The three separate images projected onto the curved wall were synthesized so that they appeared to be one complete image subtending for the participant a 165-degree useful field of view horizontally and a 55-degree useful field of view vertically. Participants sat in the driver's seat of a full-sized 1985 Acura Integra RS, which was positioned in the center of the WES. Participant responses were collected via a Nighthawk 4402 data collection computer connected to a hand-held button switch. See Figure 1 for a schematic of the WES and associated computers.

Experimental Procedures

Participants were asked to sign the Human Subjects Consent form. They were then seated in the driver's seat of the Acura Integra and were provided with a hand-held button. Participants were instructed to view an approaching vehicle and to press the button when they believed that the vehicle would collide with their vehicle. The computer-generated driving scenario for all trials consisted of a standard four-way intersection. The scenario indicated that the participant was positioned a few feet into the intersection waiting to make a left-hand turn. See Figure 2 for a depiction of the driving scenario.

Participants performed 3 practice trials and 60 experimental trials. The first practice trial depicted a white vehicle (a Lotus Esprit) on the road to the participant's immediate left, traveling at a constant velocity of 12.00 m/sec the entire distance to the participant. The second practice trial depicted the white vehicle traveling toward the participant at a constant velocity of 15.64 m/sec. At 2.49 sec before reaching the participant, the vehicle became occluded by a bush. The third practice trial was identical to the first and second except that the vehicle simply disappeared from the scenario 1.95 sec before colliding with the participant's vehicle. The participant's task for each of the practice trials was to press the hand-held button when it was believed that a collision with the approaching vehicle would have occurred. The test trials were identical to the second and third practice trials except that the approaching vehicle traveled at a constant velocity of 15.64, 18.88, or 20.11 m/sec. In an effort to control for possible confounds due to relative size effects, it was decided to either remove or occlude

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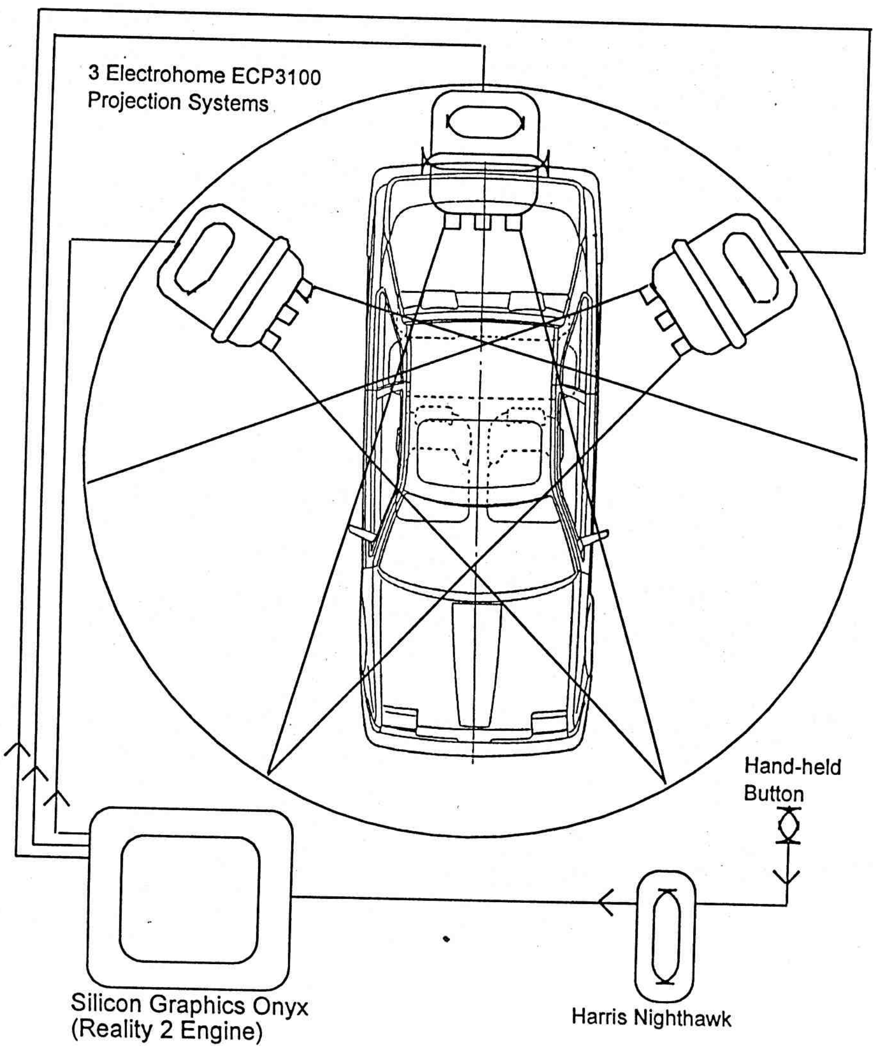

FIGURE 1 Schematic representation of wrap-around environment simulator. The useful field of view for the driver horizontally and vertically was 165 degrees and 55 degrees, respectively.

the approaching vehicle at identical points in space and to keep actual viewing times constant across conditions.

The independent variables of interest were the type of research scenario used to test estimates of TTC, the age group of the participants, the sex of the participants, and the velocity of the approaching vehicle. The dependent measure was the estimated TTC of the approaching vehicle.

Experimental Design

Estimates of TTC were analyzed in a 2 by 2 by 2 by 3 (age group by sex by research scenario by vehicle approach velocity) mixed analysis of variance with age group (young or old) and sex as between-subject variables and research scenario (removal versus occlusion) and vehicle approach velocity (15.64, 18.88, or 20.11 m/sec) as within-subject variables. The alpha level was set at .05 and significant differences were distinguished by using Tukey's HSD post-hoc test.

EXPERIMENTAL RESULTS

There was a main effect for the research scenario, $F(1, 36) = 44.24$, $p = <.01$. This effect is illustrated with reference to the differing degrees of accuracy at the three different velocities investigated (Figure 3). The means for the occlusion and removal research scenario were 1.95 and 1.65 sec, respectively. Results of the overall accuracy analysis indicated a main effect for vehicle velocity, $F(2, 72) = 15.33$, $p = <.01$ (Figure 3). Means for the 15.64, 18.88, and 20.11 m/sec vehicle velocities were 1.96, 1.76, and 1.68 sec. In addition, there was an age-by-research-scenario interaction, $F(1, 36) = 7.23$, $p = .01$ (Figure 4), and a sex-by-research-scenario interaction $F(1, 36) = 4.35$, $p = .04$ (Figure 5). No other main effects or interactions were significant.

DISCUSSION OF RESULTS

The primary finding of the present study is that the type of research scenario presented to drivers influences the accuracy of TTC

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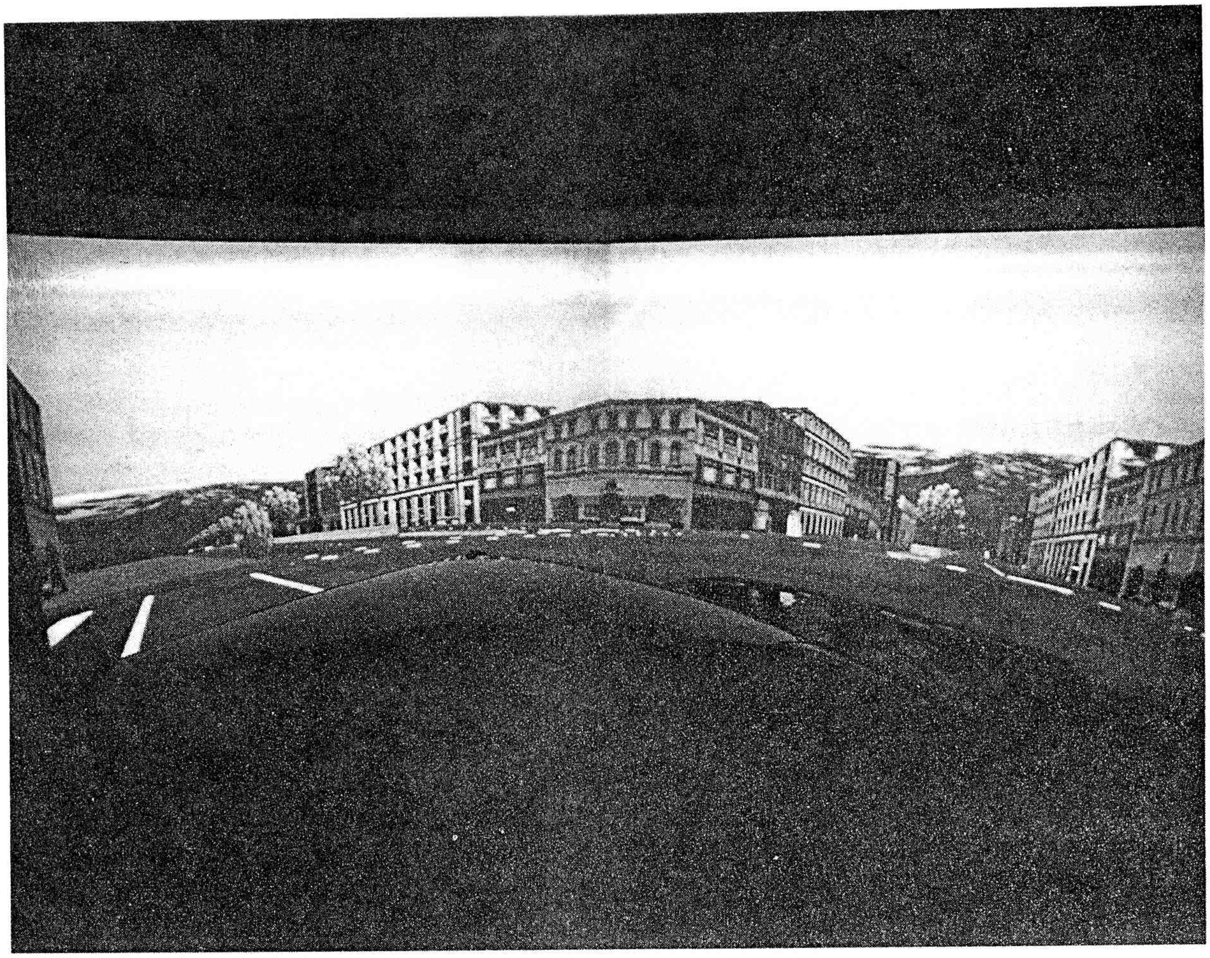

FIGURE 2 Depiction of driving scenario. (Note that this is only an approximation of the actual scene; there are inherent limitations in viewing three-dimensional surfaces in a two-dimensional representation.)

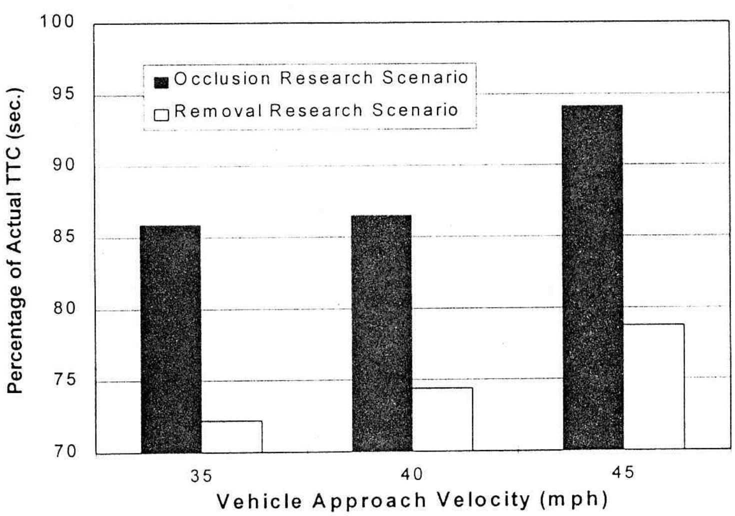

FIGURE 3 Main effects for research scenario and vehicle approach velocity as shown by interaction between vehicle approach velocity and research scenario. Scores are shown as a percentage of true TTC.

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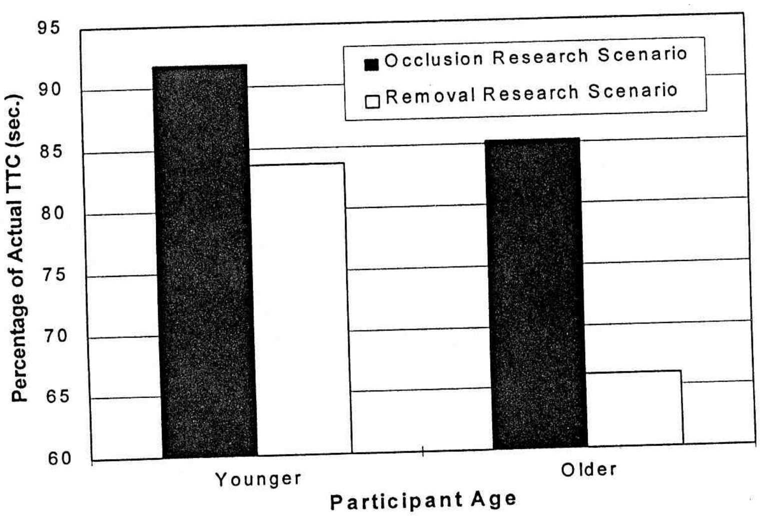

FIGURE 4 Interaction between driver age and research scenario as a result of increase in accuracy of estimates of TTC from removal research scenario to occlusion research scenario for older participants.

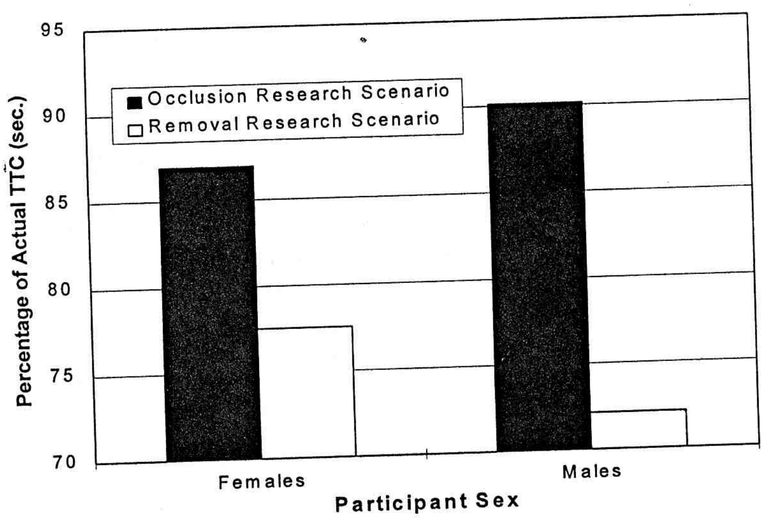

FIGURE 5 Interaction between sex and research scenario. (Note that accuracy of TTC estimates increased for both men and women when viewing occlusion research scenario, but benefits from occlusion research scenario were more pronounced for men than for women.)

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estimates. Specifically, as indicated in Figure 3, the present findings indicate that drivers estimated TTC more accurately when they viewed the more ecologically valid occlusion research scenario as compared with viewing the traditional removal research scenario. In addition, as indicated by Figure 3, drivers viewing the occlusion research scenario underestimated TTC significantly less than when they viewed the removal research scenario.

These findings lend strong support to the contention that researchers should begin to adopt research methodologies that accurately reflect situations occurring in real-world settings. By ignoring the natural context in which the process or behavior under investigation occurs, researchers risk acquiring artificial results that may have no strong relationship to real-world skills. In particular, the tendency to underestimate TTC has been problematic for nearly 40 years. Researchers posit that drivers may be underestimating TTC to create a larger margin of safety or that drivers have an innate tendency to underestimate TTC. The current findings suggest that the problematic underestimates by drivers in previous TTC studies may be accounted for by a faulty research scenario, a scenario researchers were forced to use because of technological limitations. With increases in computing power, graphical resolution, computer programming flexibility, and three-dimensional modeling, researchers can now more accurately reflect real-world situations and processes.

In addition to the main effect for the research scenario, interactions associated with individual characteristics were found. In particular, older subjects improved proportionately more than younger subjects when the research scenario changed from removal to occlusion. This might be explained by any number of reasons; however, it is clear from much work in gerontology that older subjects are disproportionately disadvantaged by more complex stimuli. Therefore, the novel and unusual nature of removal might well be expected to affect older individuals more than younger ones. Further, older individuals have more experience in real-world judging of occluded objects and therefore may have improved accordingly.

With respect to differences according to sex, men benefited more than women from the change from removal to occlusion scenario. It is interesting to note that the order of superiority changed as a function of the research scenario. In consequence, previous results concerning age and sex effects on estimates of TTC (*7,8,10*) are significantly affected by the present finding, given the interactions noted. It remains to extend the investigation of research scenario effects on TTC over a larger range of times and distances. If the reported effects hold under these extended conditions, the fundamental pattern of results and consequent practical and theoretical interpretations that have been presented will have to be rethought.

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