

A Military/Civilian Dual-Use Visual Perception Laboratory
for Investigating Vehicle Detectability

Thomas Meitzler, Darryl Bryk, Richard Goetz, Euijung Sohn, Grant Gerhart,
Robert Karlsen

US Army Tank-Automotive and Armaments Command
Research, Development and Engineering Center
Warren, MI

R. Darin Ellis
Wayne State University

Gary Witus
Turing Associates

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Abstract

According to 1990 NHTSA statistics, traffic accidents cause \$135 billion in damage to the American consumer annually, exclusive of pain and suffering. Approximately 30% of these accidents are related to driver perception problems and 14% occur at intersections. The National Automotive Center (NAC) visual perception laboratory (NAC-VPL) at the US Army Tank and Automotive Command in Warren, MI emulates driver highway visual conditions, allows researchers to measure the driver probability of detection of vehicles under different circumstances.

U.S. Army TANK-automotive and
ARMAMENTS Command

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Introduction

According to 1990 NHTSA statistics, traffic accidents cause \$135 billion in damage to Americans annually, exclusive of pain and suffering. Approximately 30% of these accidents are related to driver/vision problems and 14% occur at intersections. In 1994 the U.S. Army Tank - Automotive and Armaments Command (TACOM) and General Motors Corporation (GM) undertook a Cooperative Research Development Agreement (CRDA). The objective of the TACOM/GM-CRDA was to transfer military research and technology regarding the detectability of vehicles in natural settings. The ongoing research program involves both empirical investigation and computational model-based analysis.

The civilian use of this research is similar to the military need for the model: Understanding the visual-perceptual process of target detection permits accurate prediction of vehicle detectability against various backgrounds (Meitzler, et al., 1994; Meitzler, 1995; Tidhar, et al., 1994). For military applications, detectability needs to be minimized (i.e., camouflage), while the detectability of civilian vehicles should be maximized from a safety standpoint. An in-depth understanding could enable informed tradeoffs between various aspect of vehicle design. Critical to this endeavor is the collection of human observer performance data in controlled but naturalistic settings. This paper describes the laboratory setting, the hardware and software used for experimental control, and results from a representative experiment using a signal detection theory paradigm.

Laboratory Arrangement and Facilities

General Environment

The TACOM Visual Perception Laboratory was built to provide to the military and commercial sectors a full-scale environment in which to precisely record subjects' visual

detection behavior with naturalistic images. The facility is housed in a 2,500 square foot area, which is divided into two areas: a testing area and a control room. The two areas are separated by a glass partition. The control room houses the computer equipment responsible for experimental procedure control and data acquisition. The testing area is sound insulated and also uses a white-noise generator to reduce auditory distractions. Illumination levels can be set with variable intensity. The walls of the testing area are painted flat black so that the facility can achieve very low ambient illumination (This is important because projection systems for digital or photographic images cannot achieve the high illumination of outdoors scenes on sunny days. The human visual system achieves its 8-octave luminance dynamic range by a process known as luminance adaptation. At any instant in time, the luminance dynamic range of the visual system is between 2 and 3 octaves, centered at the luminance adaptation level. Consequently, visual sensitivity is a function of the luminance modulation relative to the luminance adaptation level. This is also referred to as the contrast ratio. At low ambient illumination, the laboratory is able to achieve realistic stimuli illumination relative to the luminance adaptation level, even though the absolute illumination levels are significantly less than bright outdoor illumination. A garage door on an external wall allows access to the testing area for vehicles ranging in size from subcompact automobiles up to a Bradley Infantry Fighting Vehicle. Communication between the control room and the testing area is accomplished through the use of a two-way intercom.

The general lab arrangement and apparatus is depicted in Figure 1. Experimental control is accomplished with an IBM-compatible PC running the LabVIEW Version 4.0.1 graphical programming environment. Compared to writing custom software in C or C++, LabVIEW allows fast implementation of complex data acquisition and control schemes in "virtual instruments." Inputs to the experimental control virtual instrument (ECVI) include stimulus information coming from a multimedia control computer, participant-initiated experimental pacing information, and participant response information. Outputs from the ECVI include experimenter-initiated pacing information to the participant and instructions to the multimedia control computer. Both the inputs and outputs to the ECVI are described in more detail below.

The ECVI allows for real-time monitoring of the inputs and outputs of the experimental sequence, as well as facilities for data storage and maintenance.

--- INSERT FIGURE 1 ABOUT HERE ---

Control of stimulus presentation is accomplished from the multimedia control computer, a Macintosh Quadra 950 running Dataton TRAX 3.0, a software package for multimedia integration and control. TRAX uses a "device and timeline" metaphor to arrange presentation sequences, timing, and triggering events on a variety of devices. Stimulus ordering is predetermined off-line through a combination of randomization and counterbalancing appropriate to the experimental situation, then programmed into the timeline with a minimum resolution determined by the Macintosh system clock (around 15 ms). Stimulus presentation is primarily accomplished with high resolution, thin-film-transistor LCD projectors (SharpVision XGE850U), using RGB input from SONY Laser Videodisk players (LVA 3500), rear-projected onto screens which subtend 36 degrees of visual angle at a viewing distance of 2 meters. The Macintosh controls the laserdisk players. Data communications take place through the laserdisk players' serial communication ports (RS232C) via Dataton Smart Pax, custom control units designed to operate with the TRAX software. In addition to the laserdisk players, stimulus and mask presentation is provided by Kodak Ektapro 7000 slide projectors controlled by the Macintosh through their P-bus connectors, also via the Smart Pax units.

Participant input and response takes place primarily through two routes: a magnetic head tracker, and a keypad. First, the magnetic head tracker (MHT) provides real-time angular measurement of point-of-regard. This data is acquired through a Hall-effect sensor that reads signals from a transmitter (Ascension Technology). The signal information is converted from analog to digital format by a dedicated electronics unit, and then transmitted via RS-232C to the ECVI. Normally, Hall-effect sensors work on continuous alternating current (AC) magnetic fields, and are disrupted by eddy currents when used in close proximity to large metallic objects such as automobile bodies. This problem has been overcome by using a pulsed DC magnetic

field: The sampling rate on the magnetic field transmitter (10-144 Hz) is decreased so that eddy currents have time to die out before the computer determines a position from the sensor. For the particular configuration in the lab, a sampling rate of 25 Hz proved most effective *⊗ - needs period.*

Other participant-initiated input to the control computer's virtual instrument comes from a custom-wired response pad. The current configuration for the response pad is designed for vehicle detection experiments, and therefore includes buttons for "target present," "unsure," and "target absent." When the participant presses these buttons, the information is fed back to the ECVI via a National Instruments DAQ-Pad 1200 data acquisition and control unit. Participant responses, as well as head angle information are monitored in real-time and stored in experimental output files.

In addition, to the MHT and response pad, the lab is also equipped with a head-mounted eye-tracking system. Combined with the capabilities of the MHT, this unit allows measurement and recording of point-of-gaze in wide field-of-view settings. Future studies plan to investigate the properties of visual distraction, and the events and objects which lead to distraction.

For the GM-CRDA, described in more detail below, the purpose of the lab work was to collect laboratory data to calibrate the NAC-CVM and evaluate its ability to predict the human perception of oncoming traffic in an intersection crossing scenario. The more general purpose of the lab is to conduct experiments on the relationship between naturalistic visual stimuli and detection task performance, collecting data for use in: (1) calibrating and validating other computational models of visual acquisition in naturalistic detection tasks; and (2) analyzing and evaluating vehicle designs for detection probability.

Specific Arrangement for TACOM/GM CRDA

The TACOM/GM CRDA was designed to investigate environmental and target factors in vehicle detection using an intersection scenario. In addition to intersections with stop signs, any location where the driver must stop, look and proceed may lead to an accident from a failure to detect an oncoming vehicle.

The LCD projectors described above were used for displaying the left and right-side motion sequences depicting the presence or absence of oncoming traffic under various circumstances. The slide projectors were used to present high-resolution static images and equal-luminance masks to participants. Three rear projection screens, subtending a total of 184 degrees (wide) by 27 degrees (tall) of visual angle surrounded the participant observation station in the testing area. There were two gaps each measuring 38 degrees of visual angle between the center and side display screens. The instantaneous field of view (IFOV) was 0.05626 degrees/pixel, equating to a limiting spatial resolution of 8.9 cycles/degree.

The front half of an automobile, or "car buck" was provided by GM for use as the participants' observation station, thus providing a more realistic testing environment than a standard chair and "cover story" could provide. The display images filled the entire vertical field of view permitted through the car buck windows.

Methods

Stimuli and Apparatus

The stimuli were recorded at intersections of surface roads in rural Michigan. The stimuli were recorded with a Panasonic tri-detector SVHS Camcorder. The camera was placed at the head position of a nominal driver stopped at the intersection. In all conditions the 0-degree (forward) orientation of the camera was due north. The camera was leveled and then aimed at 76 degrees from the forward axis in both directions based on nominal head excursions from pilot data collected by GM personnel. Automatic luminance control was disabled (i.e. set to 0dB gain). There were three locations used for recording stimuli, referred to here as A, B, and C. Location A was a clear, open grassy area. Location B had some buildings and farm-equipment in the background. For locations A and B, scenes were recorded under clear morning (9:00AM to 12:00PM DST), clear afternoon (2:00 to 5:00 DST), and under overcast conditions in each direction. The combination of the sun's position in the sky and the direction being recorded allowed the AM and PM conditions to be recorded as "frontlit" (AM-left, PM-right) and

“backlit” (AM-right, PM-left). Location C was a wooded area. For location C, the thick tree canopy created a “dappled” lighting effect on the road surface, and the images were all recorded within 120 minutes of solar noon under mostly sunny conditions. The factors produced fourteen combinations of background scene characteristics see (Table 1). There were no parked cars or extraneous traffic in any of the recorded scenes. Under each combination of background characteristics, both target-absent and target-present scenes were recorded. For the target-present scenes three different vehicles were used: (1) a large black car; (2) a large white car; and (3) a small white car. Each of these cars made approaches to the intersection from each direction under four combinations of two factors: (1) with headlamps on and off, and (2) near versus far.

Each of these factors was incorporated into a five-digit code that uniquely identified the imagery. Fourteen left- and right-hand images were randomly paired without replacement within each of the four sky conditions (representing each of the target characteristic cells and two corresponding no-target images), with the additional constraint that left- and right-hand images came from the same location. A total of four shows of 56 images each were replicated in this manner. Each of these 4 shows were then presented to from left-to-right under the three different lab viewing conditions — unfiltered, neutral density filtered (reduced luminance), and filtered with back lighting (reduced contrast). Scene luminance was varied with a neutral density filter. The scene contrast was varied by turning on or off additional slide projectors that were focused onto the projected image, adding uniform white light. Each of the four shows was manipulated in this fashion. The presentation order was reversed for right-to-left displays, while the random image pairings were maintained.

The four shows were transferred from tape to laser compact disk for presentation through the laserdisk players. The Macintosh multimedia control computer, described above, governed the transfer of images from the laserdisk players to the projectors on cue from the ECVI. Adaptive and unobtrusive control of experimental pace was accomplished with the MHT: the participants turned their head from side to side in a natural manner, activating a “switch” in the ECVI. The dynamic stimuli of the approaching cross-traffic began when the subjects’ head

position exceeded 10 degrees (was it 10, 15 or 30?) The participants response pad was integrated into the steering wheel for the purposes of this experiment. There were six response buttons in the response pad configuration used for this experiment. For both the left and the right side of a given experimental trial, the participant was able to respond, "Yes" (target present), "?" (not sure), and "No" (no target present).

Participants

A total of 32 individuals were recruited from the general population. Participants were paid \$150 for their participation. Participants were given a Snellen eye chart acuity screening and an Ishihara Color test to screen for any vision deficiencies. The group was roughly balanced across gender. Participants were required to be between the ages of 25 and 45, to have a current driver's license, to be a high school graduate, and to be in good health. Further, participants were screened out if they were commercial drivers, had three or more points on their license in the last five years, or if they were taking medication.

Procedure

Following the screening test the subject was shown a four-minute training tape, which went into great detail about the actual protocol of the experiment. Following the viewing of the tape, the subjects were exposed to an approximate 10 minute training session in the car buck. The average time of the experiment was about three hours. In order to prevent fatigue, participants were given a break every 40 minutes and upon request during the course of the experiment. After the presentation of an image on the left or right, a slide of a blue background was presented to reduce the possibility of eyestrain during the test.

The presentation of the stimuli was arranged into four blocks of the four replicate shows. The blocks of trials corresponded to the three lab-manipulated lighting conditions, with an additional block of static images for analysis of the effect of motion. The duration of the video in each trial was 250 ms (8 frames of video), and participants were given 10 seconds to respond. Each trial was initiated when the participant's head moved 10 degrees from the forward position. Each block of trials repeated the same sequence of stimulated intersection images.

Reduction and Treatment of Data

Data reduction. Due to restrictions in stimulus preparation procedure, there was only one image per cell in the experimental design. In order to prevent the effects of learning on individual stimuli, each participant was only presented with each image once. Each trial thereby resulted in a categorical response (Y, N, ?) for each participant rather than a proportion correct or similar aggregate measure suitable for ANOVA and other statistical techniques, as well as computation of sensitivity metrics. For that reason, the participants served as replicates in the analysis, and the sensitivity metrics were calculated on the participant population as a whole. For each of the 273 cells in the design, the proportion correct (i.e., "hits" for target present frames, and "correct rejections" for target-absent frames) was calculated based on the aggregated responses of the 32 participants. Each target present frame was then paired with a corresponding target-absent frame (i.e., identical background characteristics) for further analyses.

The perception test used a 3-point rating scale for the subject response. Recall that participants were asked to respond "Y" if they were certain that there was oncoming traffic, "?" if they were uncertain whether or not there was oncoming traffic, and "N" if they were certain that there was not oncoming traffic. From this data the probability of detection and probability of false alarm was computed at 2 distinct response levels: certain detection and uncertain detection. This allowed computation of two estimates of d' for each cell in the experimental design, one estimate made at the certain (Y) response level (conservative response bias), and one made at the uncertain (Y or ?) response level (liberal response bias). The best estimate of the true d' is the average of the two individual estimates. The method of computation is described in Macmillan and Creelman (1991).

There were two major alternative theoretical models of the response process: Signal Detection Theory (SDT; Green & Swets) and Choice Theory (Luce, 1959). In SDT the psychometric measure is the sensitivity metric d' , which represents the strength of the target signal relative to the strength of the background noise in the system:

$$d' = \Phi^{-1}(1 - P_{fa}) - \Phi^{-1}(1 - P_{hit})$$

where $\Phi^{-1}(\cdot)$ is the inverse of the cumulative normal distribution function. In Choice Theory, the proportion correct measures performance, adjusted for guessing

$$P_c = (P_{hit} - P_{fa}) / (1 - P_{fa}).$$

We computed both P_c and d' at both the low and high response biases to obtain two estimates of P_c and d' . Ideally, the two estimates (i.e., conservative and liberal response bias) of d' give the same result and the two estimates of P_c give the same result. The observed differences between the two estimates give use a way to measure the noise in the experiment via the chosen psychometric function. The relative magnitude of the difference between estimates was much higher with the choice theory formulation, and therefore the SDT formulation was chosen for further analysis.

Statistical Analysis Procedures. The data were partitioned into two subsets for analysis of d' with ANOVA. The first subset compared performance with the static imagery to its corresponding dynamic conditions (experiment one). The second subset filtered out the static frames and analyzed the effect of the other independent variables (experiment two). Statistical models were specified in a general linear model using SYSTAT 7.0. Only main effects and two-way interactions were analyzed.

Results

Experiment 1

Experiment one analyzed a partition of the data focused on the question of static versus dynamic imagery. All of the cases analyzed were obtained under reduced (i.e., filtered) luminance. Main effects only were analyzed using with the General Linear Model (GLM) function of SYSTAT 7.0. Effects were significant for location, scene lighting and distance, marginally significant for car color, and non-significant for car size, headlamps, and static vs. dynamic imagery.

Scene lighting was an important factor in performance [$F(3, 588) = 8.285, p < .001$]. Backlit viewing conditions (where the cars approached from the east in the morning or the west in the evening) effected the best performance ($d' = 3.06$), followed closely by overcast conditions ($d' = 2.97$) and front-lit viewing ($d' = 2.62$). The dappled lighting condition caused the worst performance ($d' = 2.21$).

Location also had a significant effect [$F(1, 588) = 14.524, p < .001$]. Detection performance was best at location B (mean $d' = 3.06$). The grassy intersection found at location A followed, with mean $d' = 2.76$. Performance was worst at the tree-lined location C, where mean $d' = 2.21$.

The distance between the viewer and the target automobile also played a large role in performance [$F(1, 588) = 132.68, p < .001$]. The closer the approaching vehicle was, the more easily detected it was. For the near vehicles mean $d' = 3.27$, while for the far vehicles mean $d' = 2.29$.

Car color played a small role in predicting performance, but failed to reach significance at the $p = 0.05$ level [$F(1, 588) = 2.862, p < .091$]. The white cars were detected with mean $d' =$

2.86, while the black car was detected with mean $d' = 2.62$. This effect was probably suppressed in the GLM modeling, due to the fact that the average target size was smaller, and thus less detectable, with the white cars.

Interestingly, there was no difference between the static and dynamic imagery [$F(1, 588) = 1.839, p < .176$], although the effect was in the expected direction. Mean d' values were 2.83 for the dynamic imagery, while mean d' values were 2.73 for static scenes. Most of the effect was due to higher levels of Pfa in the static cases, i.e., higher false alarm rates. The levels of Pd were comparable. This is consistent with anticipated driver behavior: drivers would be expected to become more cautious under more difficult viewing conditions in order to achieve their normal levels of correct detection (Pd), by raising the bias towards positive response.

Experiment 2

Experiment 2 filtered out the dynamic images, and further explored lighting characteristics by varying scene contrast and luminance in the lab. Main effects, analyzed with GLM, were significant for natural scene lighting, location, target distance, car color, and lab-varied lighting. The effect of headlamps was not significant.

Natural scene lighting was an important factor in performance [$F(2, 886) = 17.467, p < .001$]. Backlit viewing conditions were best for performance (mean $d' = 2.77$), followed closely by overcast conditions (mean $d' = 2.67$). Front-lit viewing (mean $d' = 2.34$) and dappled lighting (mean $d' = 1.99$) conditions caused the worst performance.

Location also had a significant effect [$F(2, 886) = 4.201, p < .015$]. Detection performance was best at location B (mean $d' = 2.67$), followed by location A followed (mean $d' = 2.54$). Performance suffered most at location C, where mean $d' = 1.99$.

The distance between the viewer and the target automobile also played a large role in performance [$F(1, 886) = 207.7, p < .001$]. For the near vehicles mean $d' = 2.99$, and for the far vehicles mean $d' = 2.01$.

Car color reached significance [$F(1, 886) = 12.062, p < .001$]. The white cars were detected with mean $d' = 2.59$, while the black car was detected with mean $d' = 2.31$.

The lab-based manipulation of contrast & luminance also had an effect [$F(1, 886) = 2.862, p < .091$]. Unattenuated lighting created the best viewing conditions (mean $d' = 3.29$). Participants performed worst under attenuated luminance and contrast (mean $d' = 1.47$).

Discussion

The results of this experiment were largely in line with results expected from basic research on visual perception. Rephrasing the experimental manipulations into factors commonly seen in basic lab research, we see the effect of visual perception mechanisms at work in a more “real-world” detection task: acuity and spatial frequency sensitivity (DeValois & DeValois, 1990; Sanders & McCormick, 1987), as well as color processing and contrast sensitivity (Blackwell & Blackwell, 1971; Boynton, 1992; DeValois & DeValois, 1993).

With the exception of target distance, the scene characteristics (Table 1) had much more of an effect on performance than target characteristics (Table 2). This is an important result from the standpoint of the perception laboratory’s mission: The methodology captured the variation in difficulty that occurs across various intersection crossing scenarios. Both the stimulus preparation and presentation and the experimental paradigm and data analysis techniques were shown to be well-suited to the investigation of vehicle detectability. While main-effects alone were considered here, the fact that the scene background characteristics had such a strong effect also suggest the need to carry out more design-specific investigations (such as a more in-depth

investigation of daytime use of headlamps) with a range of background characteristics. A series of well-designed experiments would almost certainly discover interaction effects between various background characteristics and design interventions.

Overall, the most important factor was target distance. For a given target object size, the visual angle subtended by the target is smaller at greater distances, the smaller the target size (or similarly, lower observer acuity), the lower the probability of detection. Thus, the vehicle distance factor can be understood in terms of acuity and target size (in visual angle). However, the absolute size of the target was not necessarily the only piece of spatial information that was used to determine the presence or absence of the target. The size of the target relative to distracting information in the scene is also important. That is, if there is distracting information with similar spatial content in the scene, then the target will be harder to detect (Duncan & Humphreys, 1989). Thus the visual context of the scene must be taken into account before generalizing these results: It may be the case that a small target is easier to detect (than an larger target) when it has less spatial content overlap with its respective distractors.

Location and scene lighting, which were partially confounded, were also significant factors in both experiments. The effect of these factors can largely be understood in terms of color and luminance contrast. Relative to Location 3, Locations 1 and 2 provided uniform lighting on uniform backgrounds. In both terms of color contrast and luminance contrast, the target "stood out" against the background at the first two locations: the black and white cars were detected on fields of blue sky and green/brown grass. The dappled lighting condition of location 3 was probably more difficult in two regards. First, the background was "broken up" with dark and bright patches, and the intermediate color information was effectively removed from the images by the shadows and glare spots. Second, this same lighting pattern was applied to the target, masking the contrast seen in the other two locations at the target edges.

Compared to the environmental task factors, the effects seen for vehicle characteristics were small (car color) or non-existent (headlamps). Car color was significant, and in the expected direction, with white cars being more detectable. Note, once again, though that before generalizing the results, one must take the whole visual scene into account. The white cars would have been much less visible under certain circumstances (e.g. snow).

The lack of an effect of headlamps here was surprising, given the conventional wisdom in this area (Rumar, 1980). One explanation of the lack of effect is the suppression of "real-world" headlamp luminance as a product of the photographic techniques. That is, the brightness that one perceives when gazing directly at headlamps is much higher than when viewing a photograph of the same headlamps. Analyzing accident statistics from 1980-1990, Elvik (1993) found that the accident reducing effect of daytime running lights was only present under certain circumstances. Therefore, there may be environmental circumstances (not present in this experiment) which would produce a large enough effect to overcome the limitations of the photographic representation. Clearly, more research in this area is warranted.

Conclusions and Future Directions

The laboratory described in this paper is a flexible environment capable of faithfully recreating the visual perception task faced by drivers, yet at the same time the lab allows the experimenter to tightly control environmental and task variables, as well as closely monitor experimental participants' performance. The generalized signal detection paradigm for measuring performance has a solid foundation in engineering, psychological and psychophysical theory, yet is well suited to the applied analysis of vehicle detectability.

Future work for the TACOM vision perception laboratory will concentrate in the two basic areas: (1) collecting data for the calibration and validation of computer models of visual