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# Development and Evaluation of New Anchors for Ratings of Driving Workload

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DRIVER INTERFACE

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Older drivers stop driving for several reasons, including being overwhelmed by the workload of the primary driving task. Unfortunately, most driving studies (including those measuring driver distraction and overload) describe workload qualitatively, not quantitatively. A simple way to quantify workload is to ask drivers to rate it while showing them anchor clips (e.g. this scene is 2, that scene is 6) to aid repeatability.

To validate new anchor clips of road scenes for workload ratings, 16 subjects (8 age 18-30, 8 age >65) drove simulated expressway scenarios and rated the workload of 28 scenarios relative to the new anchor clips, and for 10 of them that duplicated video clips from real expressways, rated the video clips as well.

Mean workload ratings from the 2 presentation methods were highly correlated (r=0.84). Workload ratings were correlated with the logarithm of the distance to the lead vehicle (r=-0.75), the number of vehicles visible (r=0.72), the distance to the side vehicles (r=-0.35), and lateral lane position (r=0.74). Workload can be estimated as 8.53-3.18*Log(Gap) + 0.28*MeanTrafficCount + 4.70*MinimumLanePosition - 0.10*StandardDeviationOfSideVehicleGap, with the $R^2$ of 0.89.

To refine the anchor clips, 18 subjects (6 age 18-30, 6 age 35-50, 6 age >65) were shown static scenes in which the field of view (120, 150, 180 degrees), and the rear scene (nothing, 3 mirrors, panoramic mirror) varied. Subjects recalled where vehicles were shown (2-11) and ranked scenes from most to least preferred. Scenes with 120- or 180-degree fields of view showing a rear scene are recommended for the anchors.

Researchers are encouraged to quantify workload using the anchored rating method and the associated equations given their repeatability and ease of use.



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# Development and Evaluation of New Anchors for Ratings of Driving Workload

## UMTRI Technical Report 2012-14, May 2012

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## ISSUES

1. How and where can the anchor clips be presented in a real vehicle?
2. How can the anchor clips be improved from those in the previous SAVE-IT and M-CASTL studies?
3. How repeatable are the ratings of the video clips?
4. How consistent are the workload ratings scenarios when watching clips with the workload ratings of the same scenarios when driven in the driving simulator?
5. How well is the workload estimated for this experiment with the new anchors and what are the resulting equations?
6. How does the current study compare with the previous studies in terms of (a) the resulting equations and (b) equations with the same factors?
7. What else should be shown in the anchor clips?

## EXPERIMENT 1 – WORKLOAD RATINGS IN SIMULATOR

## METHOD

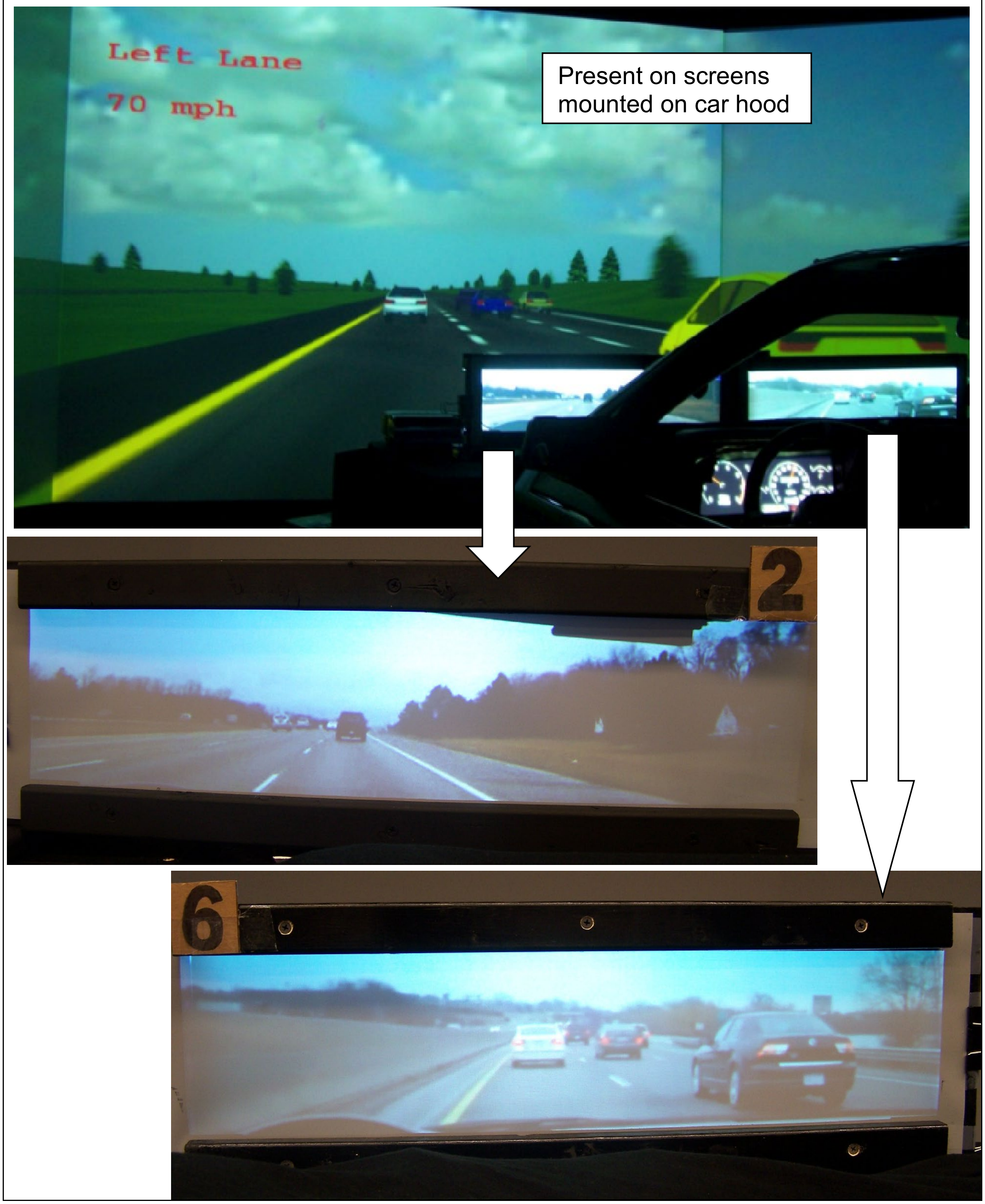
16 subjects

| Age | Women | Men |
|---|---|---|
| Young (18-30) | 4 | 4 |
| Old (>65) | 4 | 4 |

1. Drive 28 expressway scenarios twice in driving simulator
2. Rate workload relative to 2 anchor clips (ratings of 2 (low) and 6 (high) except for 2 scenarios (1 start, 1 transition)
3. Rate workload of video clips of 10 of the 28
4. Complete post test survey & recall where vehicles appeared (situation awareness test)

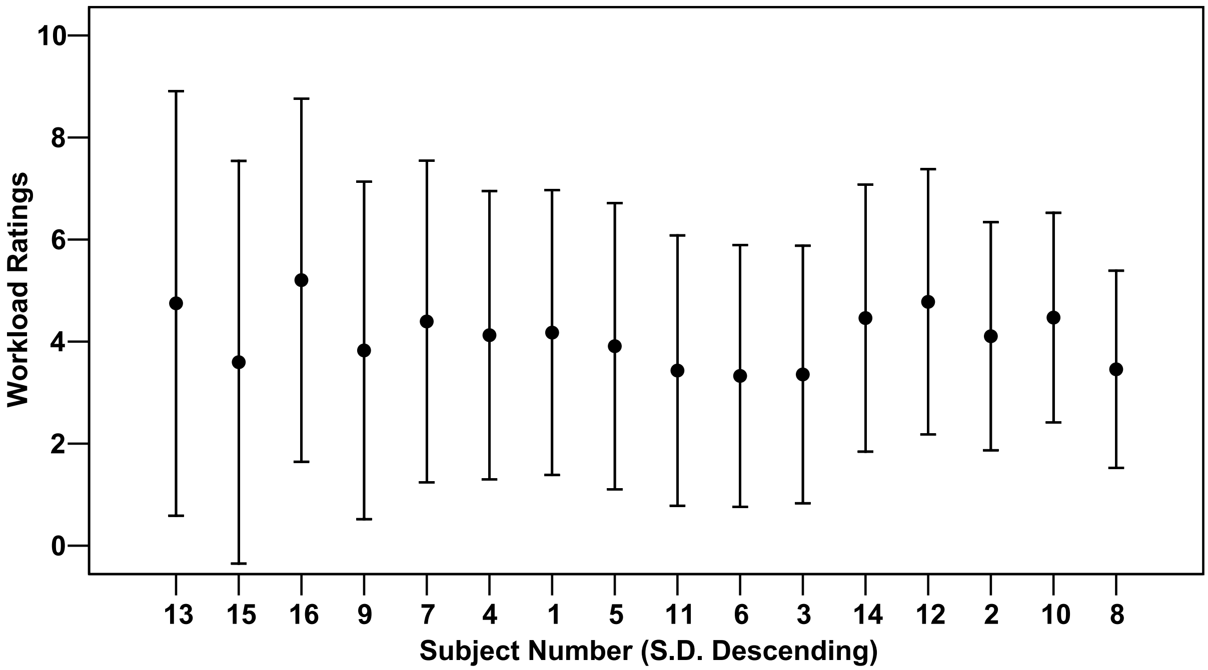
## RESULTS

**1. How and where can the anchor clips be presented in a real vehicle?**



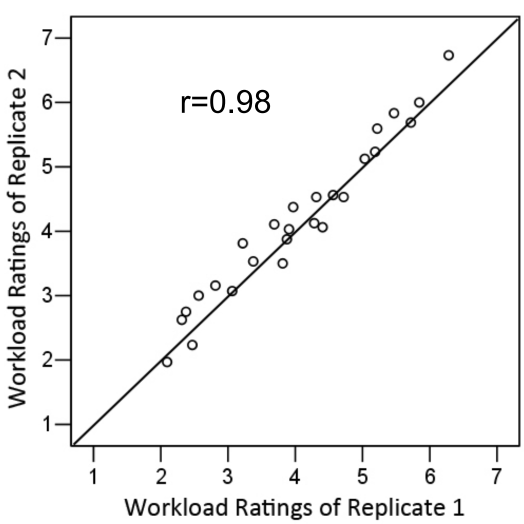
2. **How can the anchor clips be improved from SAVE-IT and the previous M-CASTL study?** (New clips were recorded.)

Greater resolution, in color, wider field of view, closer to driver's eye point, window frame and A-pillars in view to provide relative location cues

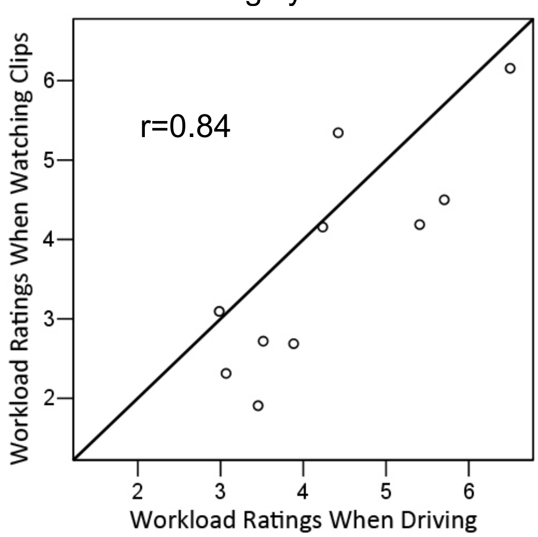



Result: All subjects used a wide range of ratings in contrast to the prior study.

3. **How repeatable are the ratings of the video clips?** – Highly repeatable




4. **How consistent are the workload ratings scenarios when watching clips with the workload ratings of the same scenarios when driven in the driving simulator?** – Highly consistent



5. **How well is the workload estimated and what are the resulting equations?** - see below

6. **How does the current study compare with the previous studies in terms of (a) the resulting equations and (b) equations with the same factors?**
   * same factors are in 2-factor equations with similar weights
   * variance accounted for is similar.

| Category | Traffic-related Factors | Statistics | r |
|---|---|---|---|
| Interactions With Other Vehicles | Lead Vehicle Gap | Mean | **-0.71** |
| | | Maximum | **-0.72** |
| | | Minimum | **-0.68** |
| | | Standard deviation | -0.21 |
| | | $Log_{10}$ (Mean) | **-0.75** |
| | Lead Vehicle Time-gap | Mean | **-0.73** |
| | | Maximum | **-0.74** |
| | | Minimum | **-0.69** |
| | | Standard deviation | -0.22 |
| | Traffic Count (with and without platoons) | Mean | **0.72, 0.73** |
| | | Maximum | **0.72, 0.73** |
| | | Minimum | **0.72, 0.73** |
| | Longitudinal Distances to Side Vehicles | Mean | **0.71** (0.31) |
| | | Maximum | **0.72** (0.27) |
| | | Minimum | **0.68** (0.35) |
| | | Standard deviation | 0.20 (-0.35) |
| Subject's Vehicle Longitudinal Control | Speed | Mean | 0.04 |
| | | Maximum | 0.09 |
| | | Minimum | -0.01 |
| | | Standard deviation | **0.41** |
| | Acceleration | Mean | -0.08 |
| | | Maximum | 0.12 |
| | | Minimum | -0.21 |
| | | Standard deviation | 0.39 |
| Subject's Vehicle Lateral Control | Lane Position | Mean | **0.58** |
| | | Maximum | **0.43** |
| | | Minimum | **0.74** |
| | | Standard deviation | **-0.66** |
| | Time-to-line Crossing | Mean | -0.06 |
| | | Maximum | -0.05 |
| | | Minimum | -0.03 |
| | | Standard deviation | 0.15 |

| | | | |
|---|---|---|---|
| Other Vehicles' Dynamics | Lead Vehicle Speed | Mean | -0.14 |
| | | Maximum | 0.05 |
| | | Minimum | -0.25 |
| | | Standard deviation | 0.30 |
| | Lead Vehicle Acceleration | Mean | 0.11 |
| | | Maximum | 0.25 |
| | | Minimum | -0.24 |
| | | Standard deviation | 0.34 |
| | Side Vehicle Speed | Mean | -0.05 (-0.08) |
| | | Maximum | -0.11 (-0.07) |
| | | Minimum | -0.09 (-0.10) |
| | | Standard deviation | -0.02 (0.15) |
| | Side Vehicle Acceleration | Mean | -0.04 (-0.08) |
| | | Maximum | **-0.43** (-0.28) |
| | | Minimum | 0.25 (-0.16) |
| | | Standard deviation | -0.34 (-0.04) |

**Estimates Using New Anchors**

| Method | # Factors | Equations | $R^2$ |
|---|---|---|---|
| Stepwise with all variables | 2 | 8.33<br>-3.83*LogGap<br>+0.49*MeanTrafficCount | 0.80 |
| | 3 | 8.38<br>-3.33*LogGap<br>+0.33*MeanTrafficCount<br>+4.25*MinimumLanePosition | 0.86 |
| | 4 | 8.53<br>-3.18*LogGap<br>+0.28*MeanTrafficCount<br>+4.70*MinimumLanePosition<br>-0.10*StDevSideVehicle2Gap | 0.89 |
| Force fitting with side vehicle 1 gap | 4 | 8.66<br>-3.19*LogGap<br>+0.23*MeanTrafficCount<br>+3.92*MinimumLanePosition<br>+0.01*MeanSideVehicle1Gap | 0.87 |
| | 4 | 8.66<br>-3.18*LogGap<br>+0.23*MeanTrafficCount<br>+3.94*MinimumLanePosition<br>+0.01*MaximumSideVehicle1Gap | 0.87 |
| | 4 | 8.60<br>-3.20*LogGap<br>+0.26*MeanTrafficCount<br>+3.95*MinimumLanePosition<br>+0.01*MinimumSideVehicle1Gap | 0.87 |

**Comparison of Estimates**

| # Factors | Variables | Coefficients | | |
|---|---|---|---|---|
| | | SAVE-IT | M-CASTL 1 | This Study |
| 2 | Constant | 8.86 | 7.90 | 8.27 |
| | LogMeanGap | -3.00 | -2.52 | -3.78 |
| | MeanTrafficCount | 0.47 | 0.06 | 0.50 |
| | $R^2$ | 0.82 | 0.69 | 0.79 |
| 3 | Constant | 8.87 | 7.90 | 8.28 |
| | LogMeanGap | -3.01 | -2.51 | -3.79 |
| | MeanTrafficCount | 0.48 | 0.06 | 0.50 |
| | MeanLongitudinalAcceleration | 2.05 | 0.51 | 0.34 |
| | $R^2$ | 0.87 | 0.69 | 0.79 |
| 4 | Constant | 8.07 | 8.57 | 8.18 |
| | LogMeanGap | -2.72 | -2.72 | -3.71 |
| | MeanTrafficCount | 0.48 | 0.13 | 0.53 |
| | MeanLongitudinalAcceleration | 2.17 | -14.28 | -0.60 |
| | MinimumLeadVehicleAcceleration | -0.34 | 0.20 | 0.05 |
| | $R^2$ | 0.85 | 0.74 | 0.79 |

## EXPERIMENT 2 – IMPROVEMENT OF ANCHOR CLIPS

### METHOD

18 subjects

| Age | Women | Men |
|---|---|---|
| Young (18-30) | 3 | 3 |
| Middle (35-50) | 3 | 3 |
| Old (>65) | 3 | 3 |

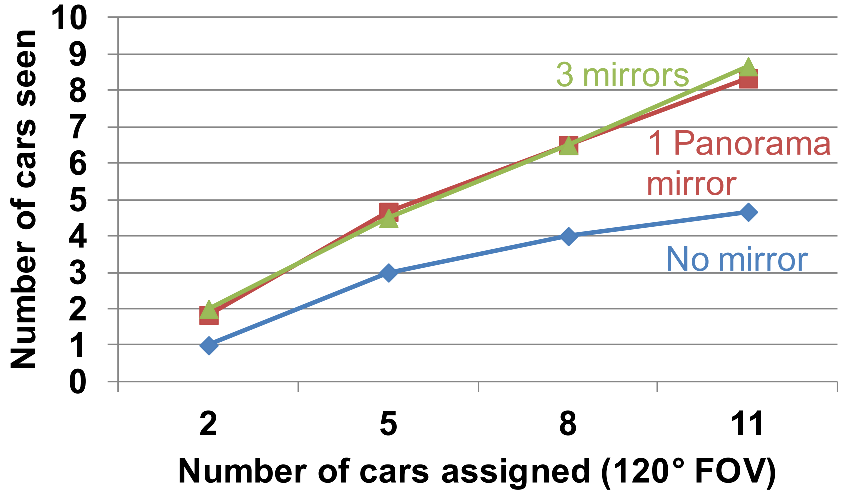
1. Shown scene (2, 5, 8, or 11 cars) and then recall car locations (4 scenes)
2. Rank order set of scenes from best to worst in terms of situation awareness

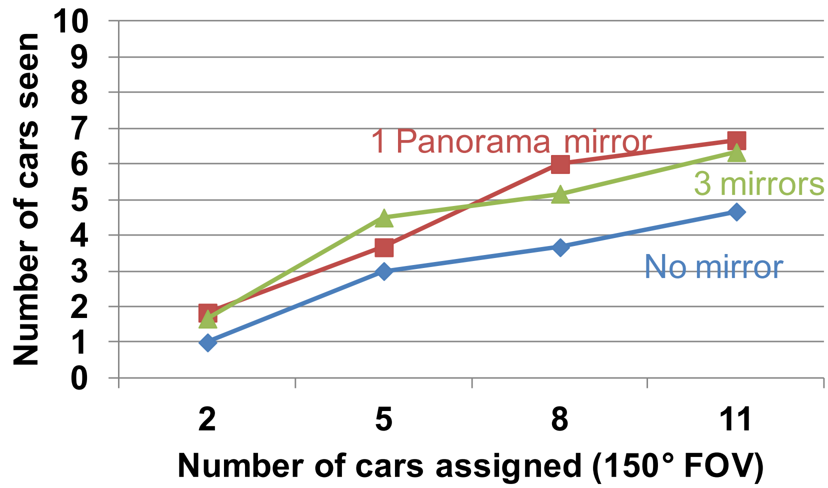
| Field of View | Rear Scene Representation | | |
|---|---|---|---|
| | No mirrors | 3 mirrors | 1 Wide Field of View Mirror |
| 120 | x | x | x |
| 150 | x | x | x |
| 180 | x | x | x |

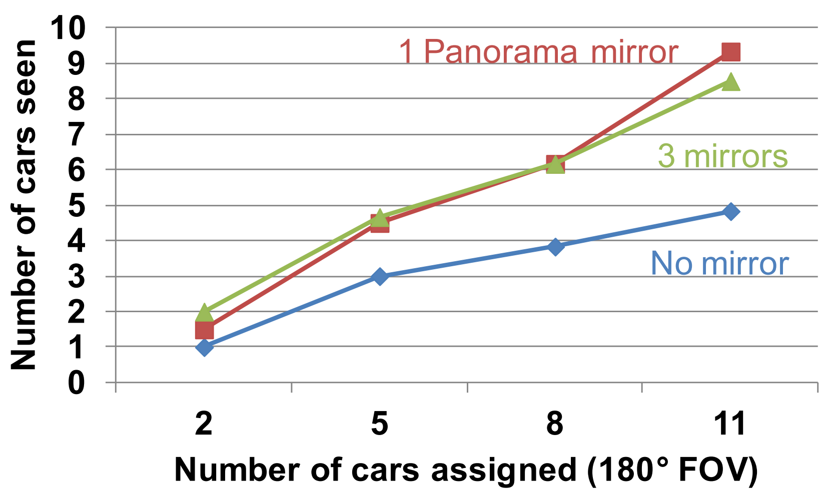
### RESULTS

1. How can the anchor clips be improved from SAVE-IT and the previous M-CASTL study?
2. What else should be shown in the anchor clips?

Recall declined for > 5 cars. Recall (situation awareness) was worst with no mirror.




The preferred anchor was a mirror or mirrors with a 120- or 180-degree field of view.

| Rank | 2 Cars | | Mean Rank | 5 cars | | Mean Rank |
|---|---|---|---|---|---|---|
| | FOV | Mirror* | | FOV | Mirror | |
| 1 | 180 | 3 | 3.5 | 180 | 3 | 3.2 |
| 2 | 120 | 3 | 3.8 | 120 | 3 | 3.6 |
| 3 | 180 | 1 | 3.9 | 120 | 1 | 3.7 |
| 4 | 150 | 1 | 3.9 | 150 | 1 | 3.8 |
| 5 | 150 | 3 | 3.9 | 150 | 3 | 4.1 |
| 6 | 120 | 1 | 4.1 | 180 | 1 | 4.2 |
| 7 | 150 | N | 7.0 | 180 | N | 7.1 |
| 8 | 180 | N | 7.2 | 150 | N | 7.3 |
| 9 | 120 | N | 7.6 | 120 | N | 8.1 |
| **Rank** | **8 cars** | | **Mean Rank** | **11 cars** | | **Mean Rank** |
| | **FOV** | **Mirror** | | **FOV** | **Mirror** | |
| 1 | 180 | 1 | 3.3 | 180 | 1 | 3.4 |
| 2 | 150 | 1 | 3.6 | 150 | 1 | 3.7 |
| 3 | 120 | 3 | 3.6 | 120 | 1 | 3.7 |
| 4 | 150 | 3 | 3.8 | 120 | 3 | 3.9 |
| 5 | 180 | 3 | 4.1 | 150 | 3 | 3.9 |
| 6 | 120 | 1 | 4.3 | 180 | 3 | 4.2 |
| 7 | 180 | N | 7.0 | 180 | N | 7.1 |
| 8 | 150 | N | 7.7 | 150 | N | 7.2 |
| 9 | 120 | N | 7.7 | 120 | N | 7.9 |

3=3 mirrors; 1=1 panorama mirror; N=No mirror

## KEY CONCLUSIONS

The improved anchor clips led to ratings that were more repeatable. Anchor clips with a 120- or 180-degree field of view with mirrors were favored.

Workload ratings for watching clips were similar but not identical clips to ratings scenes while driving the simulator, which was more immersive.

The workload equations predicted the workload ratings very well ($R^2$ = 0.89).

To predict workload, the recommended equation is:

Workload = 8.53-3.18*Log(Gap) + 0.28*MeanTrafficCount
+ 4.70*MinimumLanePosition - 0.10*StandardDeviationOfSideVehicleGap).

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# INTRODUCTION

## The Problem

Driver distraction/overload is of major concern to the U.S. Department of Transportation (USDOT) and has led the USDOT to recently release guidelines for driver distraction (U.S. Department of Transportation, 2012). Typically, the least experienced and least capable drivers, namely teens and the older drives, are most susceptible to driver distraction/overload. The basic inability to perform the primary driving task simply due to overwhelming workload is one of the many reasons older drivers stop driving. (See Eby, Trombley, Molnar, and Shope, 1998 and Oswanski, Sharma, Raj, Vassar, Woods, Sargent, and Pitock, 2007 for related information.) Older drivers who have limited capacity and who may be nearing the point at which they should stop driving are often given advice to drive on less demanding roads—with lower speeds, less traffic, fewer intersections, etc. However, without a quantitative means to assess the demands of particular roads with particular traffic conditions, those recommendations are difficult to make.

However, the research need is greater than just to be able to make recommendations about roads and traffic for elderly drivers. Specifically, what is needed is a yardstick/meter stick to quantify primary task workload for driving simulators, test tracks, and public roads, so the results from multiple experiments can be compared, such as when making assessments about in-vehicle tasks being excessively demanding. How does one make that determination if some tasks were examined for a simulated expressway in the UMTRI driving simulator in the United States and others were examined on a 2-lane road in Sweden? On the surface, the 2 test conditions do not seem to be comparable.

## Prior Research

There have been some prior efforts to compute the workload of the driving situation from road geometry and traffic (e.g., Green, Lin, and Bagian, 1993; Nygren, 1995). Hulse, et al. (1989) proposed that workload could be predicted using the equation below. Unfortunately, the mathematical origins of the equation are murky. Furthermore, literature connecting this equation to objective measures of driving performance is limited.

$A = 20 \log_2(500/Sd)$ **(Sight Distance Factor)**

where $Sd$ = sight distance (m)
if $Sd > 500$, then $A = 0$
if $Sd < 15.6$, then $A=100$

$B = (100*Rmax) / R$ **(Curvature Factor)**

where $R$ = radius of curvature
$Rmax$ = maximum value of the radius of curvature
(set to 18.52 m (60.7 ft), the turn radius for a city street)

note: $R = 360X / (2\pi a)$
$X$ = arc length along the curve (m)
$a$ = change in direction (degrees)

$C = -40So + 100$ **(Lane Restriction Factor)**

where $So$ = distance of closest obstruction to road (m)
(phone pole, fence, ditch, etc.)
if $So > 2.5$, then $C=0$

$D = -36.5W + 267$ **(Road Width Factor)**

where $W$ = road width for 2 lanes (m)
if $W > 7.3$ (24 ft, 12 ft lanes), then $D = 0$
if $W < 4.57$ (15 ft, 7.5 ft lanes), then $D = 100$

Based on their research as part of the European Union SANTOS project, Piechulla, Mayser, Gehrke, and König (2002) present a very different approach based on data from subjects driving a test route that had been coded using Fastenmeier's (1995) taxonomy of traffic situations. Situations were coded on 6 dimensions: (1) road type (5 highway classes, 2 rural road classes, 7 city classes) (2) horizontal layout (curve versus no curve) (3) vertical layout (slope versus plane route) (4) intersections (4 classes) (5) route constrictions (yes/no) and (6) driving direction (straight ahead, turn left, turn right). On the test route, there were 186 scenarios, which formed 22 unique groups using the Fastenmeier scheme.

While driving, subjects looked for text on a slowly scrolling visual display. The dependent measure was the number of glances per second averaged over subjects for each of the 22 situation classes, which varied from 0.803 to 0.476. As fewer glances per second were associated with greater workload, workload was defined as the 1-mean glance frequency, an idea similar to Hulse's 1- 9 scale. Unfortunately, the authors of this report do not list those 22 situations, the glance data, or the workload estimates for them.

That information was used to develop a workload manager described in Piechulla, Mayser, Gehrke, and König (2003). (For a demo see www.walterpiechulla.de/workloadpages/index.html). As shown in Figure 1, the workload manager begins using a table of values to determine the workload due to the road segment being driven and the segment ahead using the 6 dimensions of the Fastenmeier coding scheme. Piechulla et al. postulate that looking about 5 s ahead is reasonable, and that workload experienced decays exponentially with time y=2.71866e^(-x/4.72657), where x and y are not defined. Figure 1 shows the calculation procedure proposed, presumably only for a vehicle fitted with an ACC (adaptive cruise control) system similar to that in the BMW test vehicle, pre-2003). In brief, the calculation involves determining if a vehicle is in range (120 m). If yes, then the workload is increased by 10 percent. If an intersection is in view (presumably 5 seconds), then the workload is also increased by 10 percent. Hard braking (in excess of 1 m/s$^2$ or 0.1 g) also increases workload, and ACC operation (or at least the ACC system in Piechulla's pre-2003 BMW) reduces it by 8 percent. As shown in the figure, passing (overtaking) and rapid approach all alter workload.

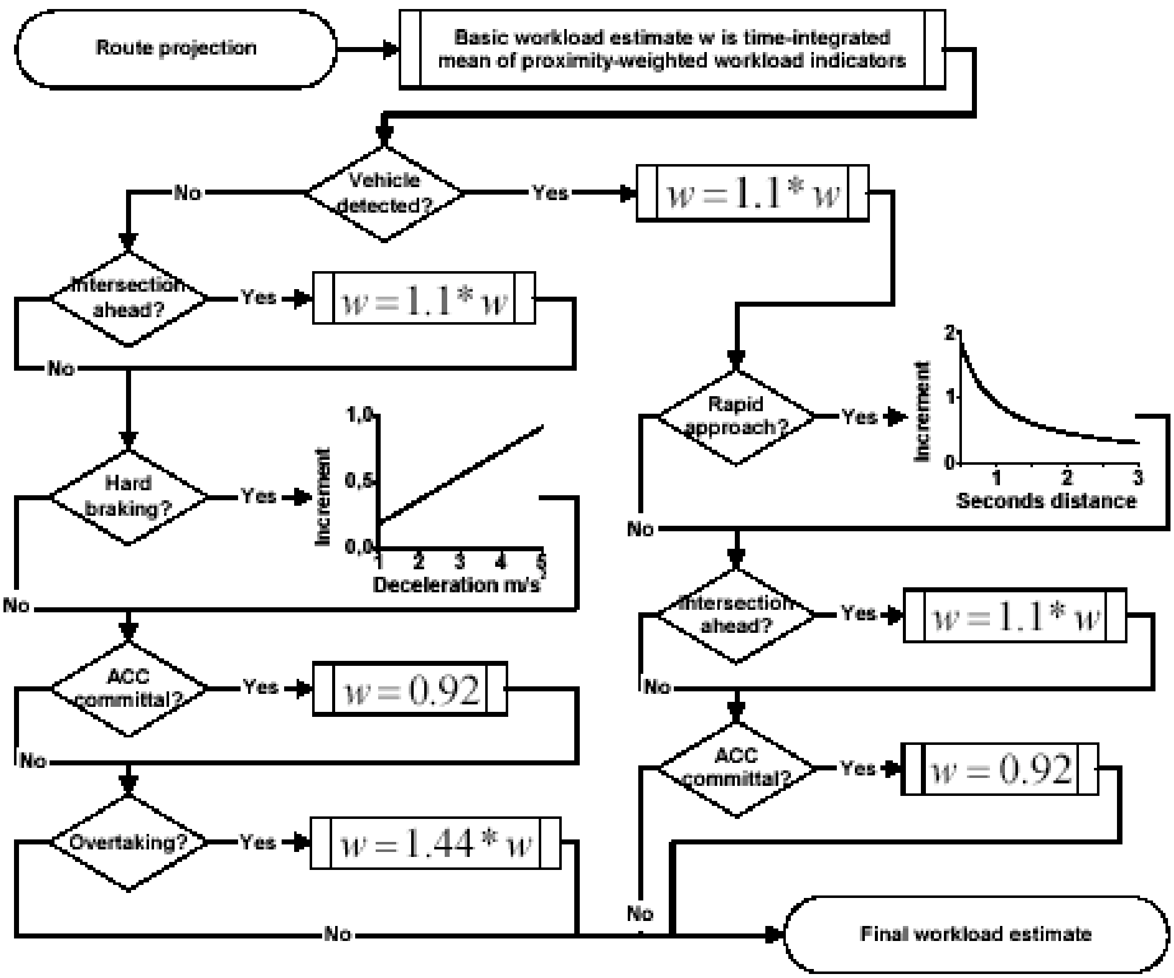


Figure 1. Adjustment of Workload Estimates in Piechulla Model

The model proposed by Piechulla et al. is quite interesting as it utilizes data from the vehicle to estimate workload and includes the road ahead (and planning needed), not just the current segment. Interestingly, the model only considers a single lead vehicle, not multiple vehicles as traffic, though it does include overtaking maneuvers. Overtaking is assumed to mean going past another vehicle in another lane, not a flying pass that involves a lane change.  This is an important assumption because overtaking leads to one of the largest increments in workload.

A more detailed model from an earlier paper, translated here (Milla, 2007, personal communication) from the German original (Piechulla, Mayser, Gehrke, and König, 2002), appears in Figure 2.  In contrast to the work of Nygren, Piechulla et al. (2002) suggest only very modest increases in workload due to darkness (2.6 %), rain (5 %), a wet surface (2.5 %), and ice (10 %).

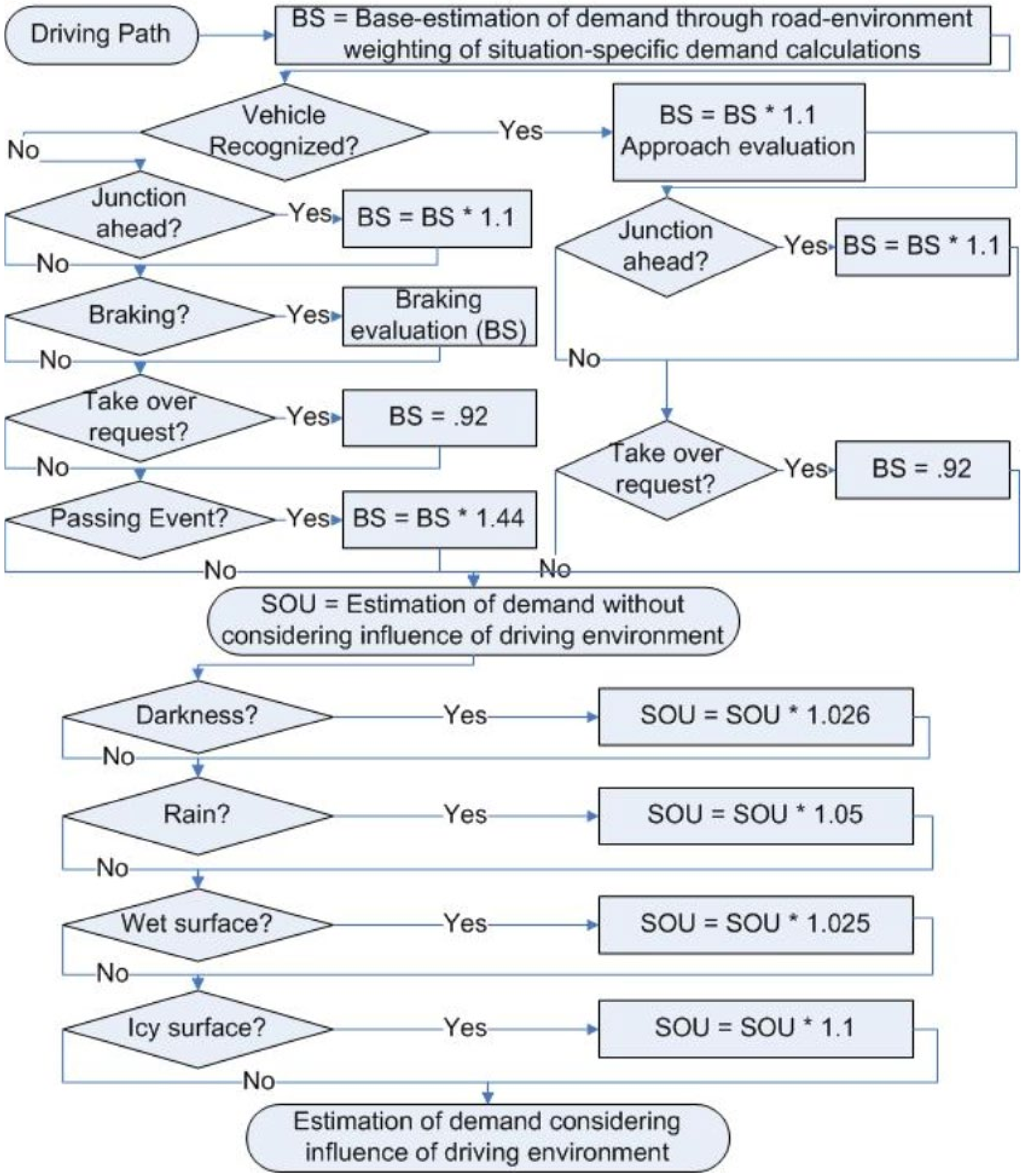


Figure 2. Model Presented in Piechulla, Mayser, Gehrke, & König, 2002 (translated)

Given that there are some ideas about how workload could be predicted, how should it be measured? DeWaard (1996) notes that measures of driving performance can be divided into 4 categories: (1) primary task performance (e.g., standard deviation of lane position, time to line crossing, speed variance), (2) secondary task performance (e.g., response time to peripheral light), (3) physiological (e.g., heart rate variability), and

(4) subjective (e.g., NASA Task Loading Index (TLX, Hart & Staveland, 1988), the Cooper-Harper Rating Scale (Cooper and Harper, 1969), and the Subjective Workload Assessment Technique (SWAT - Reid, Shingledecker, and Eggemeier, 1981)). In addition, primary task workload can be assessed using visual occlusion (Senders, Kristofferson, Levison, Dietrich, and Ward, 1967; Green, Diebol, Park, and Ho, 2011.) (See also Hicks and Wierwille, 1979; Ostlund, Peters, Thorslund, Engstrom, Markkla, Keinath, Horst, Juch, Mattes, and Foehl, 2005; Angell, Auflick, Austria, Kochhar, Tijerina, Biever, Diptiman, Hogsett, and Kiger, 2006.) Unfortunately, there is no consensus in the literature as to which measurement is best, though for primary task performance, standard deviation of lane position and NASA TLX are reported most often. For additional information, see Green (1993), O'Donnell and Eggemeier (1986), and Verwey and Veltman (1996). The authors would argue that subjective measures are often the easiest to collect.

The absence of a repeatable, direct, easily obtained, and universally used measure of workload, along with the absence of equations to predict primary task workload from road geometry, traffic, and other factors led to a series of studies conducted at the University of Michigan Transportation Research Institute (UMTRI). As part of the SAVE–IT project, Schweitzer and Green (2007) had drivers rate the workload of various road scenes, which were recorded from the vehicle's point of view. The test and anchor road scenes were collected as part of the Advanced Collision Avoidance System (ACAS) field operational test. Driver ratings of primary task workload were relative to 2 anchor clips showing Level of Service (LOS) A and E (light and heavy traffic) that were looped and always in view. Overall, ratings typically ranged from about 1 to 10. Ratings were remarkably repeatable and consistent, with ratings for a particular clip being some value plus or minus a half of a point.

Using logistic regression, predictive equations were developed relating workload ratings to driving performance statistics that were associated with the clips shown to drivers. Some 87 % of the rating variance was accounted for by the following expression:

Mean Workload Rating (across subjects) = 8.87 - 3.0*LogMeanGap + 0.48*MeanTrafficCount + 2.05*MeanLongitudinalAccleration

Gap (to the lead vehicle) and traffic count were both determined by the adaptive cruise control radar.

Considering that most human factors researchers are pleased when an experiment accounts for 50 % of the variance, accounting for 87 % of the variance is remarkable. Thus, the method developed was extremely reliable, easy to carry out, and using the ACAS data, led to equations for predicting workload.

However, the Schweitzer and Green study (2007) only involved drivers rating video clips of driving rather than on actual driving. To overcome this problem, Green, Lin, Schweitzer, Ho, and Stone (2011) had subjects drive expressway scenarios in a driving simulator with about half of the scenarios driven closely replicating the clips shown in the prior experiment (to provide for a between-experiment comparison). In addition, the subjects rated the workload of the expressway scenarios again using the anchor video clips.

The mean workload ratings of video clips from this experiment were highly correlated with the mean ratings from the SAVE-IT study (r=0.97), though the overall ratings were lower. Further, the ratings of video clips from this study were highly correlated with the workload ratings for the scenes when driven (r=0.92).

However, the most important finding was that the mean workload rating while driving could be estimated as 5.13 - 0.02*mean gap, where the mean gap was measured in meters. This equation accounted for 69 % of the variance of the workload equations. Also well correlated with the workload ratings while driving were the mean traffic count (r=0.65), the log10(gap) (r=-0.83), and the inverse gap (r=0.78). Thus, this study showed that the workload rating method could provide reliable workload ratings for simulated driving, and the factors that led to workload were the same for watching clips of road scenes as well as driving them (at least, in a driving simulator).

This study also identified a few opportunities for improvement in the test method. First, a few subjects ignored the instructions and did not make the ratings relative to the anchors, suggesting a need for changes in the instructions. Second, deficiencies in the anchors made the ratings less consistent than they could be, suggesting a need for new anchors. The original anchor clips were selected from the ACAS field test, which was the best available field test data available at UMTRI at the time when the Schweitzer and Green study was conducted. For Schweitzer and Green's study, it was important to have a wide range of clips for comparison with the anchor clips that were recorded consistently—same field of view, same resolution, etc. Furthermore, to provide the independent measures needed for the regression analysis, data for several hundred variables describing each scenario (speed, lane position, etc.) were needed.

Unfortunately, the ACAS clips were recorded at 1 Hz in black and white, which made them a bit hard to follow when played back. The field of view was limited, so all relevant traffic was not visible, especially vehicles to the side that boxed in the subject's vehicle. Also, all of the situations examined were steady state—the traffic was not maneuvering. Furthermore, to help subjects comprehend movement sequences, clips were played back at 2 Hz. To overcome these and other concerns, this study was conducted.

Seven issues were examined.

1. How and where can the anchor clips be presented in a real vehicle?
2. How can the anchor clips be improved from those in the previous SAVE-IT and M-CASTL studies?
3. How repeatable are the ratings of the video clips?
4. How consistent are the workload ratings scenarios when watching clips with the workload ratings of the same scenarios when driven in the driving simulator?

5. How well is the workload estimated for this experiment with the new anchors and what are the resulting equations?
6. How does the current study compare with the previous studies in terms of (a) the resulting equations and (b) equations with the same factors?
7. What else should be shown in the anchor clips?

To address these issues, 2 experiments were conducted, (1) a driving simulator experiment in which subjects responded to improved anchor clips while driving a mixture of old scenarios plus new scenarios that contained maneuvers, and (2) a recall and rating experiment in which subjects recalled the location of vehicles in various displays and then ranked those displays from best to worst based upon the situational awareness they afforded.

# EXPERIMENT 1: SUBJECTIVE WORKLOAD RATINGS IN THE DRIVING SIMULATOR - ISSUES & METHOD

### Issues

This experiment addressed all of the project issues, listed below, except for part of issue 2 and 7 concerning the content of the anchor clips.

1. How and where can the anchor clips be presented in a real vehicle?
2. How can the anchor clips be improved from those in the previous SAVE-IT and M-CASTL studies?
3. How repeatable are the ratings of the video clips?
4. How consistent are the workload ratings scenarios when watching clips with the workload ratings of the same scenarios when driven in the driving simulator?
5. Using data collected with the new anchors, how can workload be estimated? How similar are the new equations to those based on the original anchors?
6. Do the estimates based upon the new anchors account for greater variance than those obtained with the old anchors?
7. What else should be shown in the anchor clips?

### Comparison of the Old and New Anchor Clips

As was noted previously, there were a number of problems with the old anchor clips, representing limitations in the recording and storage capability present when the ACAS data was collected. Those limitations are not present in current in-vehicle systems due to reductions in camera cost, and the cost, size, and power requirements of storage devices.

An experimenter driving an instrumented 2006-07 Honda Accord LX sedan fitted with an UMTRI-designed custom data logging system collected the new clips. For stability, the camera that recorded the clips used in this experiment was mounted near the driver's eye point (as shown in Figure 3). The built-in cameras associated with the logging system did not have the desired image quality.

Figure 3. Location of the Camera Used to Record Clips

The data logging system had forward radar (to provide the distance to other vehicles nearby), recorded information from the CAN bus (e.g., subject vehicle speed and acceleration), and had other sensors as well. These data were needed to develop new workload equations, as they were the independent variables. The test vehicle is described in reports from the IVBSS project (Green, Sullivan, Tsimhoni, Oberholtzer, Buonarosa, Devonshire, Schweitzer, Baragar, and Sayer, 2008).

Image Quality: Wider Field of View, Higher Update Rate, Greater Resolution, Color

The anchor clips were video-recorded in the 120-degree field of view (with Canon VIXIA HF200 + WD-H37II wide-angle lens), wider than the camera used previously (that had a 90-100 degree field of view). Thus, cars close to the side of the subject's vehicle, especially those that may box in the subject, were visible in the clips. The stream rates were in 1 and 1.5 Mbps, which was the VCD quality using MPEG-1 compression. The update rate was 25 frame/s, much higher than previous anchor clips record at 1 frame/s, played back at 2 frame/s. Further, the resolution was 856 x 480 pixels and the compression ratio was better than previous clips. The sharpness and aliasing were also greatly improved, as shown in Figure 4. In the previous anchor clip, the aliasing effect was apparent. (See the car's tire.) In the previous anchor screen shot, the shape of the left rear wheel cover could not be recognized. The sharpness improvement could be found especially in the edge of the image (e.g. the edge of car's left C-pillar), which was jagged in the old anchor clip. Finally, the new anchor clips were recorded in 32-bit color, versus monochrome previously.

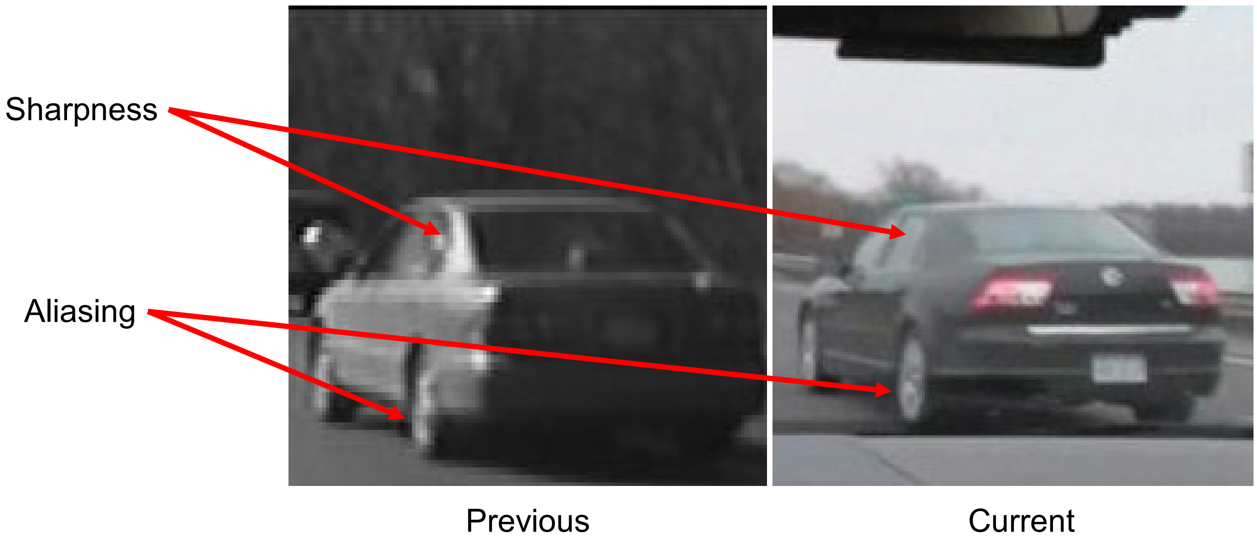


Figure 4. Sharpness and Aliasing Improvement of Anchor Clips

<u>New Presentation Location: On the Hood</u>

In the third generation UMTRI Driving Simulator, there are 5 forward screens, covering a 200-degree field of view. The screen used to show the anchor clips was the center left channel, covering from 20 to 60 degrees left of straight ahead. Although this location makes sense for a simulator experiment, it is not a realizable location in a real vehicle and thus alternatives were sought.

Informal assessments examined presenting the anchor clips on in-vehicle displays, such as on a laptop computer or even an LCD display. However, those assessments identified numerous problems in mounting the display, potential distraction, and potential blockage of key controls and displays. However, most important was that the images were too small—that key details, such as a vehicle in a mirror, were too difficult to see. There were also problems in comparing the anchor clip with the forward scene if the anchor clip was too far from the line of sight. One solution was to not show the anchor clips at the same time, but to devote the entire image to 1 clip at a time, showing them in sequence. This required remembering 1 anchor, which made the workload rating process more difficult. This could potentially lead to inconsistent ratings.

The solution was to mount 2 projection screens side by side on top of the hood (Figure 5), back projecting the images on to those screens using LCD projectors. Each screen (made from a sheet of milky white drafting Mylar) was 22 in wide x 5 in high, so cushions were laid on the seat to increase subjects' eye height and to avoid subjects' vision being blocked by the screens. The aspect ratios were fairly similar, 5:1 for the old anchors and 4.4:1 for the new ones. The only concern was that the luminance of the screens for anchors was higher than the simulator projectors because of the projection distance and the lack of a set of neutral density filters. However, the excess luminance did not seem to interfere with subjects viewing the anchor clips. Figure 6 shows what drivers saw.  The LCD projectors used to show anchors were an Epson EMP-X5 (2200 lumens, for anchor 2) and an Epson EMP-730 (2000 lumens, for anchor 6).


Figure 5. Anchor Projection Screens on the Hood


Figure 6. Anchor Clips As Seen by Subjects

Admittedly, the wooden frame used in the simulation would not survive a road journey, and a test vehicle would look a bit odd with 2 large screens on the hood, but the study was a proof of concept and was sufficient for that purpose. Some version of this concept could be implemented on road.

Again, the goal was to make the anchor clip screen as close as possible to occupying the same visual angle as the road scene, and as close as possible to it to facilitate comparison. In this case, the anchor clip was less than half the visual angle of the real scene.

<u>Shortened Anchor Clip Duration</u>

The original anchors were 30 s long and looped. As they were played back at 2x, they looped every 15 s. However, over the 30 s time period, it was apparent that workload shown changed—cars were much closer or farther away, both ahead and in adjacent lanes. Thus, the duration had to be shortened, which was to 5 s. This duration was chosen as a practical compromise of having enough movement so the unfolding situation could be seen, but not so long that it would be unstable or one in which unwanted objects would appear that could demand attention (e.g., highway signs).

Added Frame of Reference

A camera mounted in front of the interior mirror recorded the old anchors. No parts of the vehicle, not even the hood, were shown, so judgments about the location of objects close to the vehicle were difficult. For the new anchors, images were recorded close to the driver's normal viewing position, with the A-pillars and interior mirror as well as the top of the dash in view to provide a frame of reference. For reasons of safety, the driver's head could not be displaced by the video camera when the scenes were recorded.

Matching the Traffic in the Old Anchors to the New Anchors

To provide a bridge between the prior and current studies, the goal was to make the road geometry and traffic in the new anchors as close as possible to the prior anchors. Key items to match were the road curvature, lane width, lane choice, and the location of all vehicles in the old anchor scenes. This could have been done by finding a time period when the expressway of interest (Interstate 94 west of Ann Arbor) was free of traffic, and having a fleet of confederate vehicles drive so that they were in locations matching those in the old clips. This was not feasible.

Thus, one of the experimenters drove on the expressway for some period of time, positioning the test vehicle so that the conditions duplicated the low and high workload conditions. Natural variations in traffic between rush and non-rush hours allowed for this to occur. Figure 7 shows the new and old clips for comparison. The clips, which show movement, are a closer match than these stills suggest. However, they are not perfect.

| | | |
|---|---|---|
| 2 | Old |  |
| | New |  |
| 6 | Old |  |
| | New |  |

Figure 7. Old and New Anchor Clips

**Simulated Scenarios Tested**

In this experiment, subjects drove in traffic and when cued by a recorded voice presented by the simulator, rated the workload of scenarios they drove relative to the 2 looped anchor clips shown on screens mounted on the hood of the car. They drove a total of 28 scenarios as shown in Table 1. Included were (1) 10 scenarios representing a wide range of workload for which there were recorded clips of driving on a real expressway, (2) 2 scenarios duplicating the anchor clips (to check the anchors), (3) 14 scenarios in which traffic systematically varied, (4) 1 starting scenario, and (5) 1 transition scenario.

All driving scenarios showed a straight section of an expressway with 3 lanes in each direction separated by a wide grassy median. Traffic consisted of up to 1 lead vehicle, 2 vehicles in adjacent lanes, and 2 platoons (1 ahead, 1 behind) of 3 cars with 1 vehicle from each platoon in each lane. The platoons, normally far ahead or far behind, had been used in prior studies to keep subjects from driving too fast or too slow. Platoons, when included, were 40-130 m ahead and 130 m behind of the driver.

Table 1. Test Scenarios

| # Scenarios (trials) | Scenarios Driven | Comment |
|---|---|---|
| 10 | expressway replication | selected from recordings to collect anchor clips to offer wide workload range to expand the equations<br>due to programming limitations, only 2 vehicles in other lanes could be presented, so the scenarios did not completely duplicate the clips<br>driven lane varies<br>after the simulator drive, the workload of the clips used to create these scenarios were rated |
| 2 | anchor | to compare ratings of clips with driving them |
| 14 | systematic variation of traffic | systematic variation of lane driven, distance to other vehicles, number of vehicles present to explore those effects in a controlled manner<br>given a limited experiment duration, only a few combinations were examined<br>always drive in right hand lane to facilitate comparison and simplify the design of the experiment |
| 1 | starting trial | for getting up to speed |
| 1 | transition trial | need to move vehicles for position of 1 scenario to another |
| 28 | total | |

Table 2 shows the expressway scenarios created to duplicate recorded video clips. Notice that the lane driven by the subject varied, which sometimes required the subject to change lanes before a trial began (commanded by a recorded voice and shown on the center simulator channel screen). Appendix A shows stills from a sample of the videos shown in this portion of the experiment.

Table 2. 10 Scenarios Simulated from On-Road Clips (Plus 2 Anchors)

| # | Subject | | Lead (same lane as subj.) | Other Vehicle 1 | | Other Vehicle 2 | |
|---|---|---|---|---|---|---|---|
| | Lane | mi/hr | Location | Lane | Location | Lane | Location |
| 1 | Center | 65 | 30-48 m ahead | Center | 35-45 m behind | Left | 5 m ahead +2 $m/s^2$ to 69 mi/hr |
| 5 | Right | 65 | 16-21 m ahead | Center | 3 m ahead +1 $m/s^2$ to 68 mph | Center | 70 m ahead |
| 11 | Right | 65 | 25-37 m ahead | Center | 20-25 m ahead | Center | 45-50 m ahead |
| 13 | Right | 65 | 19-22 m ahead | Center | 35-45 m behind | Center | 30-35 m ahead |
| 17-1 | Center | 70 | 41-50 m ahead | Center | 20 m behind | Left | 65-70 m ahead |
| 19-1 | Center | 70 | 21-26 m ahead | Center | 20-30 m behind | Left | 65-70 m ahead |
| 21-2 | Left | 65 | 7-10 m ahead | Center | 3-15 m ahead | Center | 35 m ahead |
| 22 | Left | 70 | 66-67 m ahead | Center | 20-30 m behind | Center | 80 m ahead |
| 25 | Left | 70 | 16-17 m ahead | Center | 20-30 m behind | Center | 25 m ahead |
| 31 | Center | 70 | 21-28 m ahead | Left | 10-15 m ahead | Left | 45-50 m ahead |
| Anchor 2 | Right | 65 | 42-51 m ahead | Center | 45-55 m behind | Center | 20-25 m behind |
| Anchor 6 | Left | 70 | 19-20 m ahead | Center | 15 m ahead -1 $m/s^2$ to 68 mi/hr | Center | 18-23 m ahead |

Table 3 shows the 14 scenarios in which lead vehicle movement and distance, and the presence of other vehicles were systematically varied. Included were 2 levels of gap between the lead vehicle and subject's car (20 m & 40 m), 3 levels of lead vehicle speed change (fixed speed, 1 $m/s^2$ acceleration, 1 $m/s^2$ deceleration), and 5 combinations involving 2 vehicles in adjacent lanes. Future studies with greater resources should examine all combinations of these factors.

Table 3. 14 Scenarios in Which Traffic Was Systematically Varied
(Subjects Drove in Right Lane Only)

| Other Vehicles (in Adjacent Lanes) | Lead Vehicle – Acceleration and Gap | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | Fixed speed | | Accelerate $+1\ m/s^2$ | | Decelerate $-1\ m/s^2$ | | |
| | 20 m | 40 m | 20 m | 40 m | 20 m | 40 m | |
| fixed speed 7 m ahead | x | x | — | — | — | — | 2 |
| fixed speed 15 m ahead | x | x | — | — | — | — | 2 |
| passing | x | x | — | — | — | — | 2 |
| fixed speed 15 m ahead<br>fixed speed 7 m ahead | x (PC*) \| x (PF*) | x | — | — | — | — | 3 |
| No side vehicle | x | x | x | x | — | x | 5 |
| Total | | | | | | | 14 |

*PC=Platoon close (40 m), PF=Platoon far (130 m)

**Test Sequence**

Table 4 shows the order in which tasks occurred. The experiment took about 1.5 hr to complete, for which subjects were paid $40. The practice trials were included to verify that subjects knew what to do and used the anchors for rating the workload. Rating the workload while driving always occurred before rating the clips, because the simulator ratings were of greatest interest and needed to be reliable without prior exposure to other rating experiences. Appendix B contains the complete set of instructions.

Table 4. Task Sequence and Durations

| # | Task | Duration (min) |
|---|---|---|
| 1 | Introduction – consent form (Appendix C), biographical information (Appendix D) instructions, vision check | 15 |
| 2 | Practice driving the simulator and rating workload | 10 |
| 3 | Drive and rate workload – order 1 | 20 |
| 4 | Drive and rate workload – order 2 | 20 |
| 5 | Post test rating of video clips (Appendix E) | 8 |
| 6 | Post test evaluation of factors that could matter | 15 |
| 7 | Pay subject $40 and sign payment form | 2 |
| Total | | 90 |

Each driving scenario lasted approximately 30 s, with workload ratings being collected for the middle 15 s of each scenario. The start and stop points for the rating period were spoken in the driving simulator. Specifically, subjects were told, “In the driving simulator session today, you will drive a wide range of scenarios and rate the workload of each. Your ratings of workload will be relative to these 2 reference clips.” After the clips were shown, they were then told, “So, if the workload of a driving scenario was equivalent to the example on the left, the lower workload level, it would be rated as 2. If the workload was equal to the scenario on the right, then it would be a 6. The greater the workload is, the larger the number will be. However, most of the situations will not be equal to those values, but may be in between, or greater or smaller. So, ratings could be 1 or 3 or 8, or even 4.5. In fact, most people find they cannot rate the workload any more accurately than the nearest ½ point. Even if you might prefer to use values other than 2 or 6 for the reference clips, please use those values.” Ratings, said aloud by subjects, were recorded on a spreadsheet by the experimenter.

At the beginning/end of trials, when subjects were not rating workload, they were sometimes told to change lanes, an instruction spoken by the experimenter and shown on the center channel screen. There were also instances where their speed needed to change (from 65 to 70 mi/hr or the reverse) to match a real-world scenario that had been recorded.

The sequence of scenarios in the driving simulator was driven twice, with the second order being the mirror image of the first. The 2 orders were counterbalanced across test blocks. Additional sequences were not used because substantial practice effects were not expected, and randomizing the sequence of trials led to vehicle repositioning movements between trials that were unnatural.

When subjects were asked in the post test to identify factors that affected workload, factors known to have effects from prior research (distance to the lead vehicle and vehicles in adjacent lanes, if the lead vehicle was accelerating/decelerating at a fixed distance, the driven speed, etc., were included as well as factors not expected to matter (color of cars in the scene) to avoid biasing subject responses.

**UMTRI Driving Simulator**

The experiment took place after the first major upgrade of the third-generation UMTRI driving simulator (www.umich.edu/~driving/sim.html). The simulator consists of a full-size cab, 10 computers, 6 video projectors, 7 cameras, audio equipment, and other items. The main functions (generating scene graphics; processing steering wheel, throttle, and brake inputs; providing steering wheel torque feedback; and saving data) were controlled by hardware and software provided by DriveSafety (Vection and HyperDrive Authoring Suite, version 1.6.2), software used at several universities and companies in the U.S.

Figure 8 shows the simulator cab and a typical forward scene from a practice drive. The simulator has a forward field of view of 200 degrees and a rear field of view of 40 degrees created by 5 forward channels and a rear channel. Each channel was 1024 x 768 and updated at 60 Hz. Depending on where the subject sat after adjusting the seat, the forward screen was 16 to 17 ft (4.9 to 5.2 m) from the driver’s eyes, close to the 20-ft (6-m) distance often approximating optical infinity in accommodation studies.

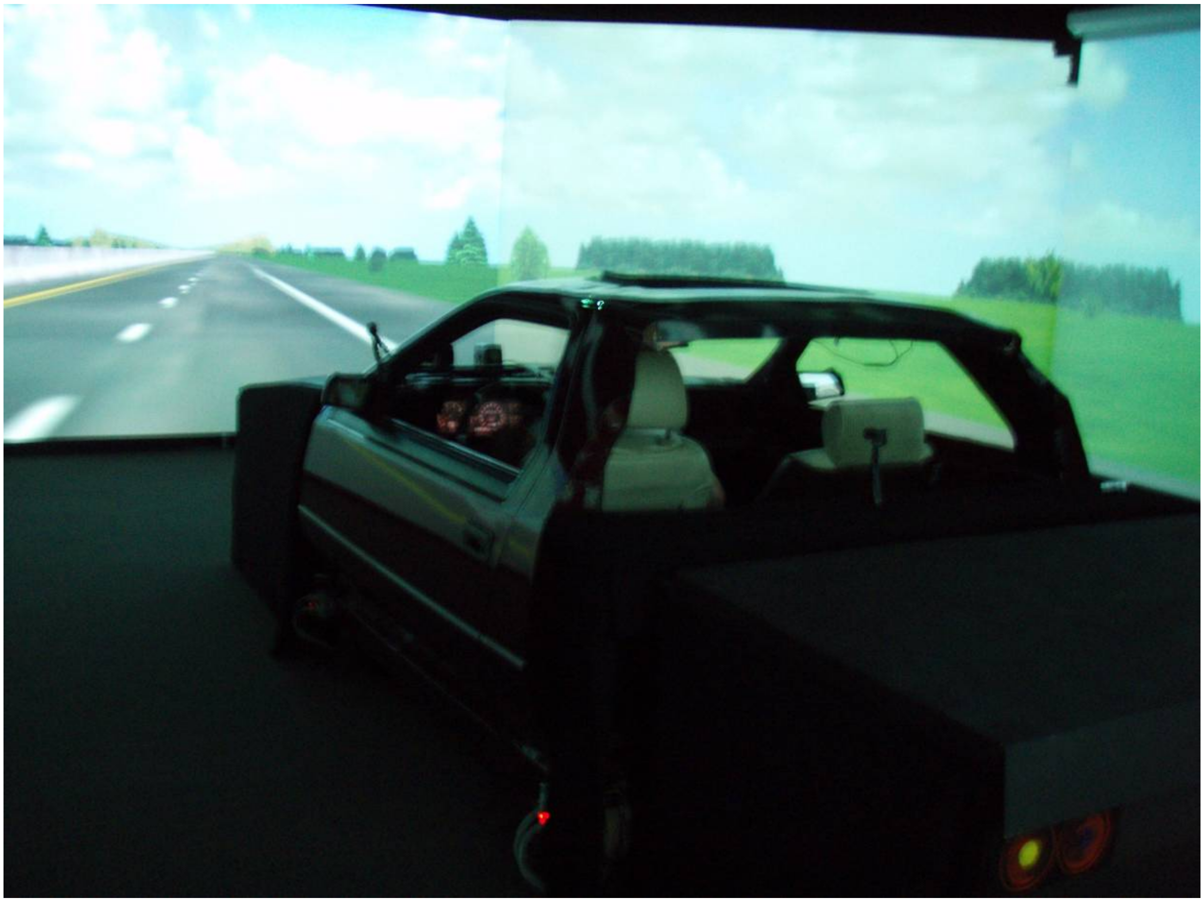

Figure 8.  Simulator cab, front screen, front-right screen, and front-side screen

The simulator was controlled from an enclosure behind and to the left of the cab.  The enclosure contains 4 quad-split video monitors that show the output of every camera and computer in the simulator, a display that shows the quad-split combination being recorded, a keyboard and LCD monitor for the driving simulator computers, and a second keyboard and LCD monitor to control the instrument panel and warning and scenario control software (Figure 9).  Also in the enclosure was a 19-inch rack containing audio and video equipment (audio mixers, video patch panel and switchers, distribution amplifiers, DVD recorder, quad splitter, etc.) and two separate racks for the instrument panel and touch-screen computers, the simulator host computers, and the 6 simulator image generators.  The instrument panel and center console computers ran the Mac OS, the user interface to the simulator ran Windows, and the simulators ran Linux.


Figure 9. Simulator operator's workstation

The vehicle cab consisted of the A-to-B pillar section of a 1985 Chrysler Laser with a custom-made hood and back end mounted on casters for easy access. Mounted in the mockup were operating foot controls, a torque motor connected to the steering wheel (to provide steering force feedback), an LCD projector under the hood (to back project the speedometer-tachometer cluster), a 10-speaker sound system (for auditory warnings), a haptic seat, a sub-bass sound system (to provide vertical vibration), and a 5-speaker surround system (to provide simulated background road noise). The 10-speaker sound system was from a 2002 Nissan Altima and was installed in the A-pillars, lower door panels, and behind each of the two front seats. The stock amplifier (from the 2002 Nissan Altima) drove the speakers.

The speedometer-tachometer display was controlled by a Macintosh computer running REALbasic and looked similar to those in an early 1990s Honda Accord.

Mounted in and around the cab were 8 video cameras. Images included the driver's face (viewed from outside and inside the cab), 2 over-the-shoulder images (showing the instrument panel), an image from the package shelf showing the instrument panel and forward scene, an image of the feet and pedals, and an image from a “floater,” a camera on a tripod that could be positioned anywhere. These images, combined with output from any of the projected images, could be recorded on videotape using a quad splitter. Real-time audio and video of simulator activity was available via a web camera mounted above the simulator control enclosure.

Figure 10 shows a close-up of the cab interior. A unique feature of the simulator is the computer-generated, back-projected speedometer-tachometer cluster.

Figure 10. View of the inside of the simulator cab
Note: The instrument panel configuration is from a prior study.

For additional information on the simulator see Green, Sullivan, Tsimhoni, Oberholtzer, Buonarosa, Devonshire, Schweitzer, Baragar, and Sayer (2008).

Critical to this project was an expressway scenario generator that allowed the test conditions to be created very quickly, with tasks that normally take months to be completed in days (Schweitzer and Green, 2009). Figure 11 shows a typical screen.

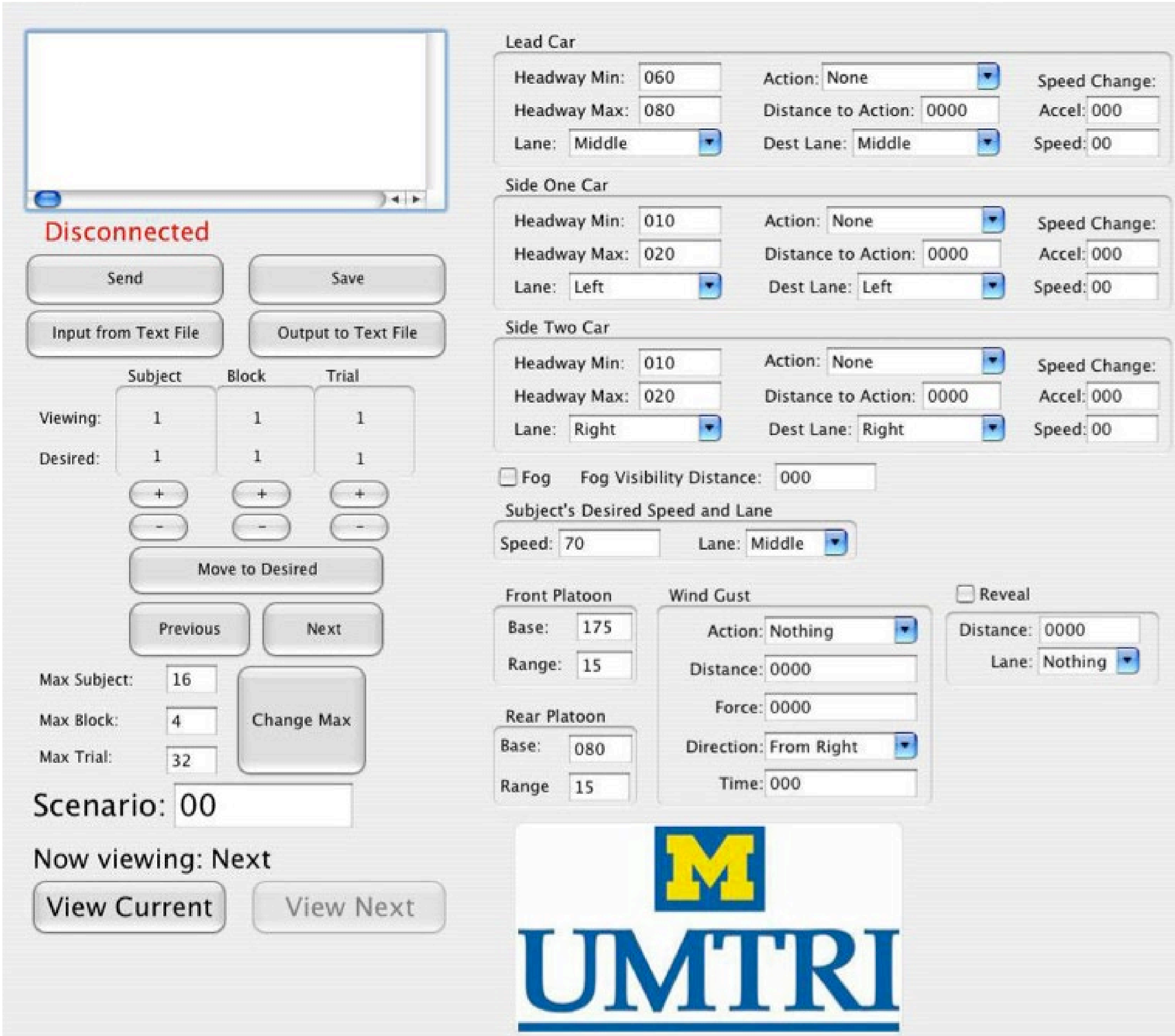


Figure 11. Expressway Scenario User Interface

## Participants

Sixteen subjects were recruited via Craigslist (Appendix F) and contacted directly by phone (Appendix G). The subjects were in equal numbers of age (18-30 yr; >65 yr) and gender (male; female) combinations in 4 groups. The mean ages of each group were 24 (young male), 22 (young female), 72 (old male), and 67 (old female). Six subjects had a record of minor crashes in the past 5 years, but they were not responsible for the crashes.

# EXPERIMENT 1 - RESULTS

As a reminder, there were 26 scenarios driven twice plus 2 transition and 2 starting trials for the 16 subjects to rate. Ratings from the starting trials (when drivers to speed up) and transition trials (when drivers switched lanes) were ignored because the workload was not stable. Thus, there should be 832 ratings (26 x 2 x 16) to be analyzed.

There were no missing data. However, 12 data points across 5 subjects were omitted from further analysis. In these 12 instances, the workload was not as intended. (See Table 5.) For most of these situations (10/12), subjects drove on the lane lines or the shoulder for the entire 15-s rating period, which would make the variable “Time-to-lane crossing” indefinable. Further, if what constituted the driven lane was uncertain, then so too would the lead vehicle be uncertain. This is important because the gap to the lead vehicle is a major factor in the workload equation. Therefore, 12 cases were removed.

Table 5. Removed Data Points and Why

| Subject # | Observations | # of Cases |
|---|---|---|
| Old female 4 | Drive on the lane lines | 3 |
| Old male 2 | Drive in the wrong lane | 1 |
| Young female 1 | Drive on the lane lines | 2 |
| Young female 4 | Drive on the lane lines | 5 |
| Young male 1 | Temporary power failure | 1 |

### How Were the Workload Ratings Distributed When Driving in the Simulator?

For workload rating equations, 26 scenarios with 2 replications were used on 16 subjects. Without those cases being removed, the 820 workload ratings were distributed as in Figure 12. Most (91 % = 743/820) of the ratings were between 2 and 6 (the ratings of anchor clips), and the distribution was right-skewed. The mean and standard deviation of workload ratings were 4.1 and 1.6. About 27 % of ratings were not given as integers, which was a greater proportion in a previous M-CASTL research project (13 %). Ideally, the percentage of integer and non-integer ratings should be equal (50 %). To encourage such non-integer ratings, modifications of the instructions could be desired. One subtle way to encourage non-integer ratings would be to repeat back subject ratings with additional detail. (“Ok, that one is rated three point zero.”) However, the possibility needs to be considered that some subjects cannot estimate workload any more accurately than the nearest integer.

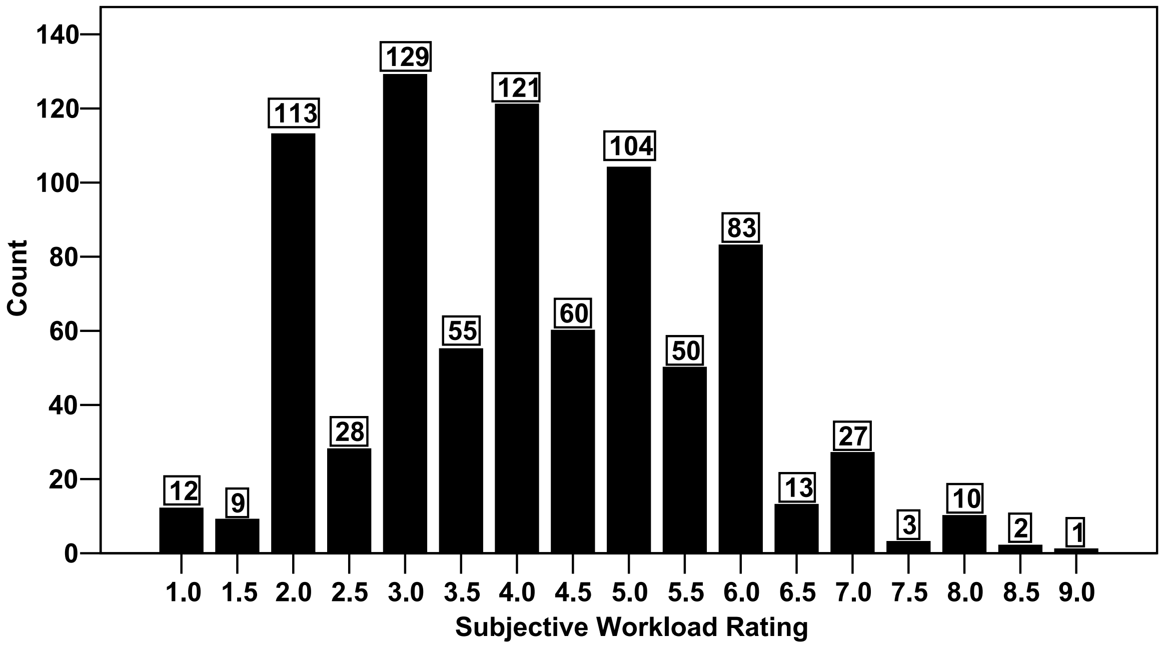


Figure 12. The Distributions of Workload Ratings

In the previous M-CASTL project, some subjects only used part of the potential range for ratings. For example, 2 subjects limited their ratings, one from 1 to 3 and the other from 2 to 4. For them, their higher workload conditions corresponded to those of other subjects, but they were responding as if the anchor clips did not exist. To overcome that problem, the instructions were modified to further emphasize use of the anchors, and checks were added to the practice task to make sure subjects followed the instructions. In this experiment, the rating ranges of each subject are shown in Figure 13. All subjects' ratings were around 4 with the smallest standard deviation being 0.97. Thus, the range limitations found previously did not occur, presumably due to the modified instructions.

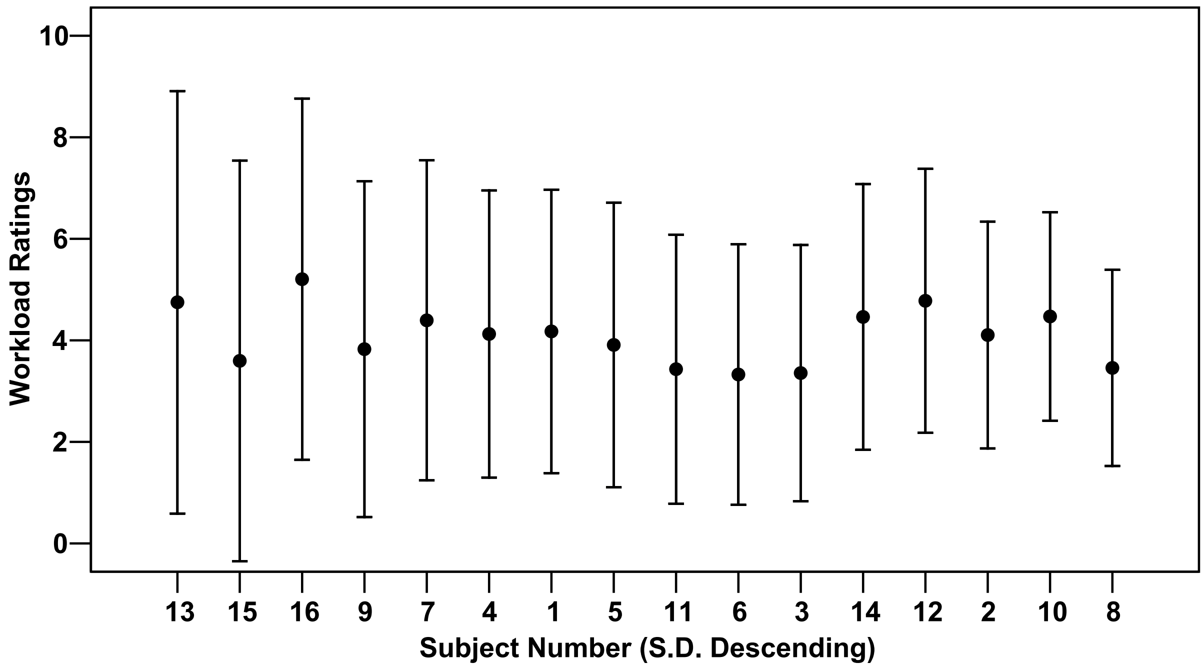


Figure 13. Mean Workload Ratings of Subjects Sorted by Standard Deviation

Figures 14 and 15 highlight the effects of age and gender on workload ratings. Ratings of older subjects were statistically significantly greater than of young ones (Mean, 4.3 vs. 3.9; SD, 1.7 vs. 1.4; $F(1, 816)=17.750$, $p<0.001$). Compared to young subjects, older subjects gave more ratings over 6. Men rated slightly lower than women (Male mean 4.0, SD 1.4; Female mean 4.1, SD 1.7; $F(1, 816)=0.930$, $p=0.335$). Male subjects' ratings located more about 3-5, but more than 10 ratings were given over 8 by women, which made the distribution less skewed and increased the standard deviation. In theory, there should be no gender or age differences because the ratings are relative to anchors. This suggests some consideration of workload independent of the anchors, an undesired outcome. Fortunately, the difference in the most extreme case (0.4 due to age) was less than the smallest scale increment (0.5).

The skewed situation was found in all cases, but the rating distribution of men was skewed more than women. Figure 16 represents the interaction between age and gender on workload ratings, which was significant ($F(1, 816)=6.110$, $p<0.05$). For male subjects, their ratings were not affected by age, but older females' ratings were higher than young females.

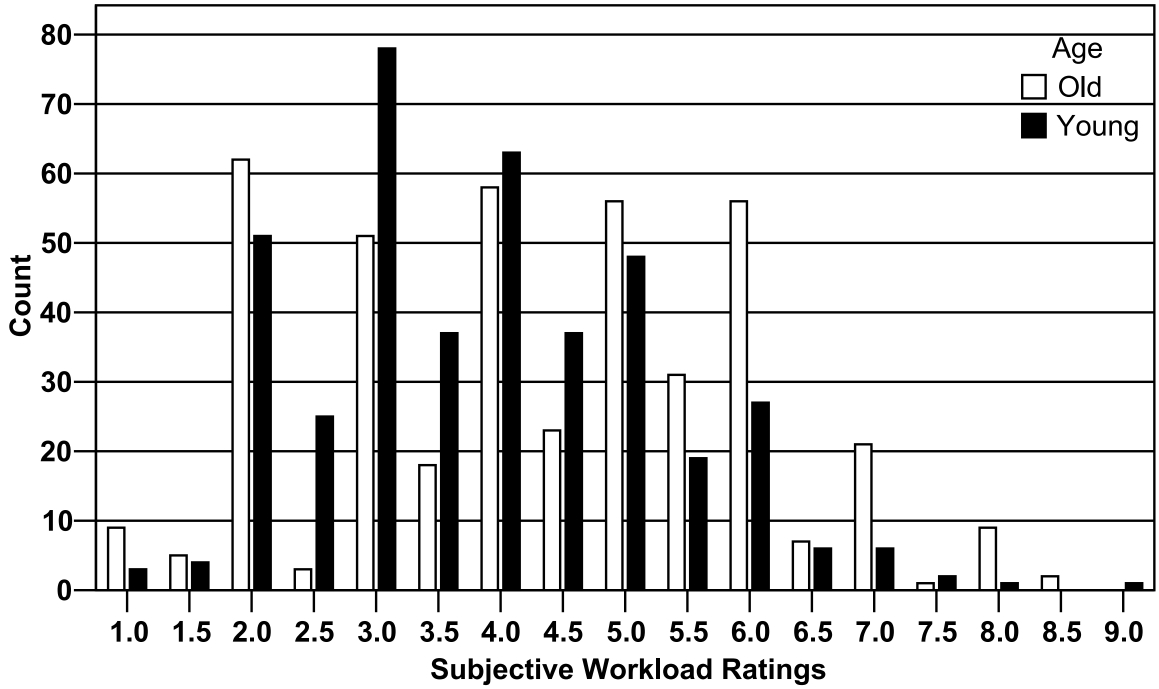


Figure 14. The Distributions of Workload Ratings by Age

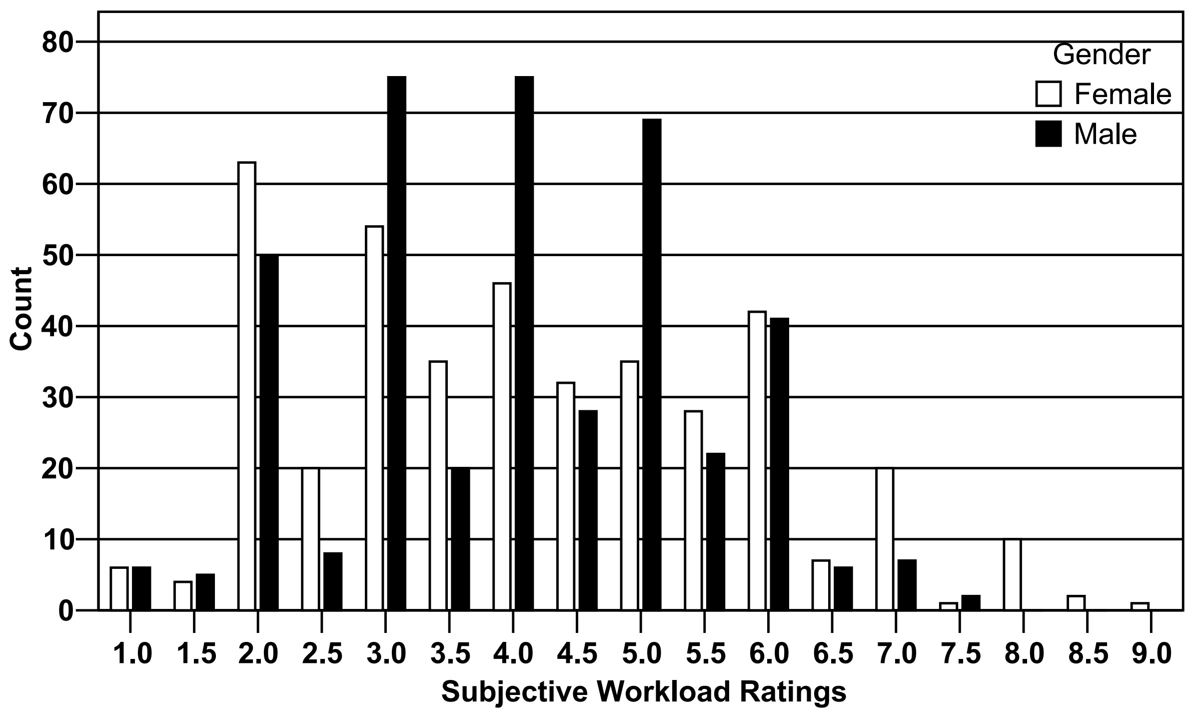


Figure 15. The Distributions of Workload Ratings by Gender

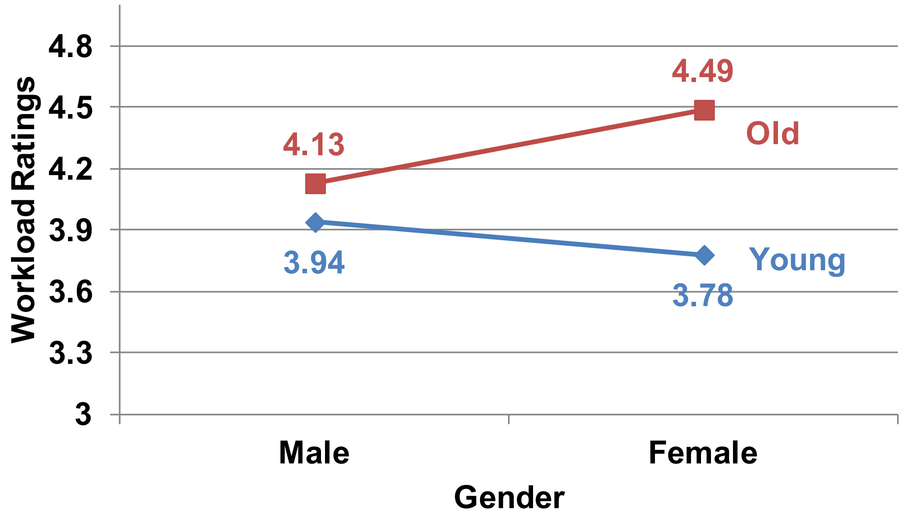


Figure 16. Workload Ratings by Age and Gender

**How Were the Workload Ratings Distributed When Watching Video Clips?**

As a reminder, for 10 of the 26 test scenarios, workload ratings relative to the anchor clips were collected both while driving them and watching clips of them (captured on an expressway). Figure 17 shows the distributions of ratings for video clips. The distribution is skewed, and 89 % (143/160) of ratings were between 2 and 6, a finding similar to that for the driving workload ratings.

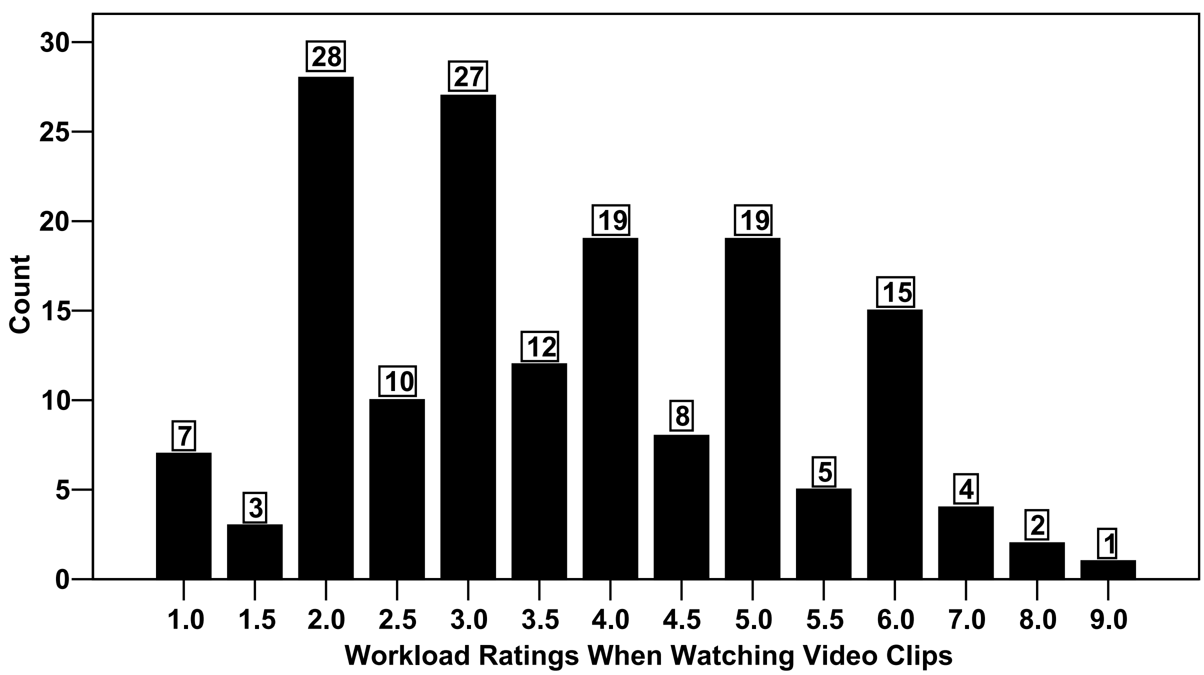


Figure 17. The Distributions of Workload Ratings When Watching Video Clips

Figures 18 and 19 show the workload rating distributions by age and gender. The means (and standard deviation) for old, young, male, and female subjects were 4.1 (1.8), 3.4 (1.4), 3.6 (1.4), and 3.8 (1.8), respectively. The age effect was significant ($F(1, 156)=7.457$, $p<0.01$), but the gender effect was not ($F(1, 156)=0.799$, $p=0.373$). There was no interaction between them ($F(1, 156)=0.483$, $p=0.488$, shown in Figure 20). Young subjects gave lower ratings, especially for young males.

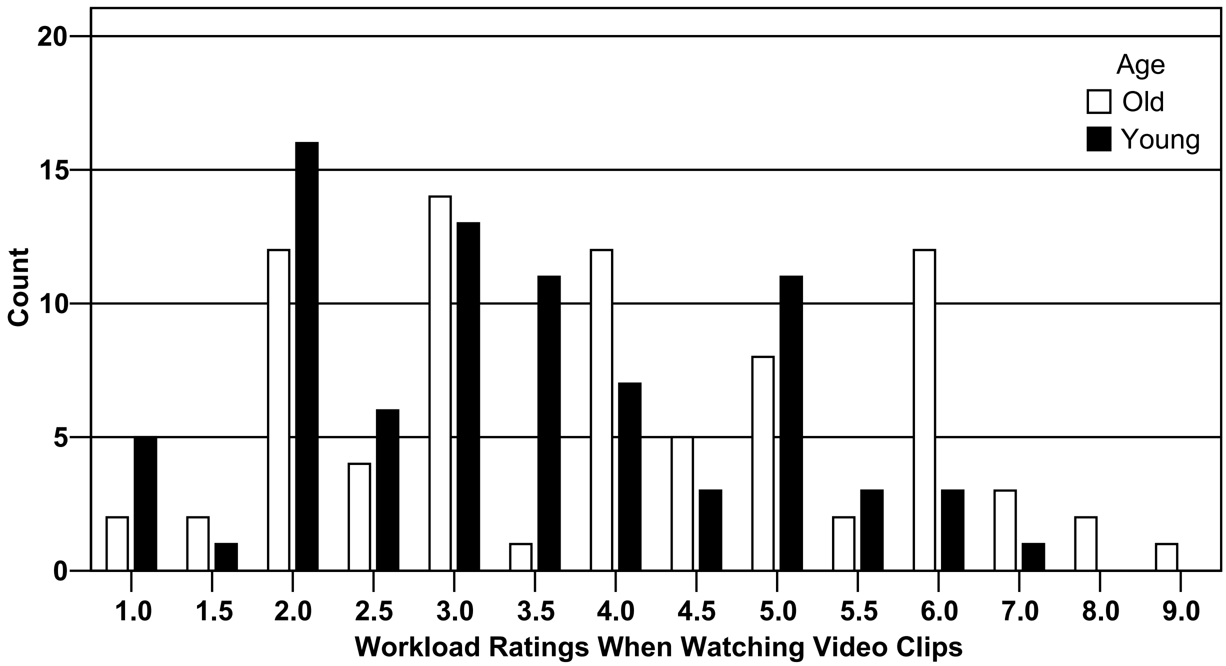


Figure 18. Distributions of Workload Ratings by Age When Watching Video Clips

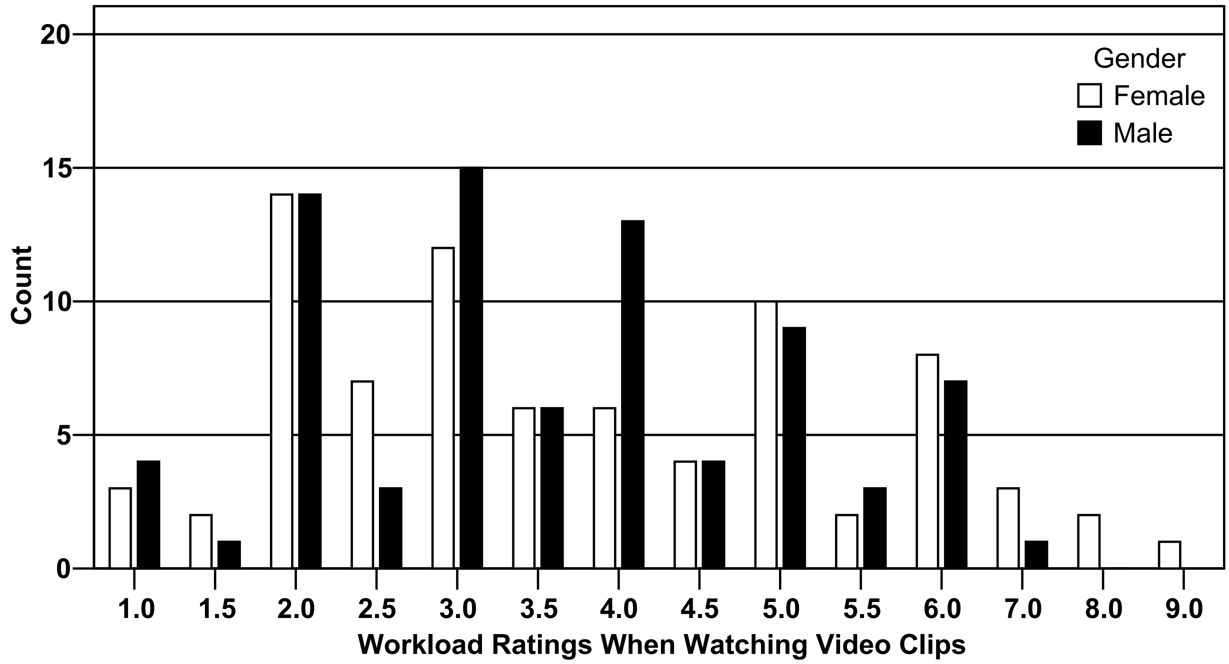


Figure 19. Distributions of Workload Ratings by Gender When Watching Video Clips

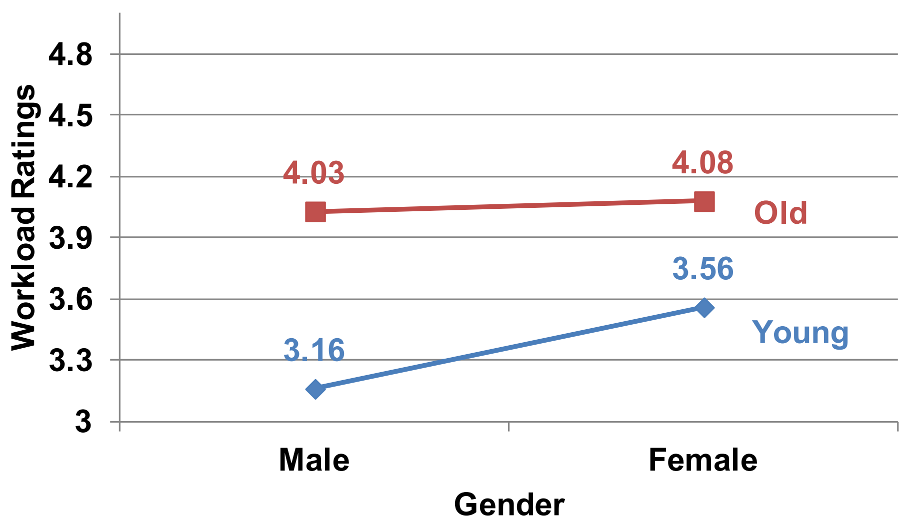


Figure 20. Workload Ratings by Age and Gender When Watching Video Clips

**How Consistent Were Repeated Workload Ratings of the Same Clips?**

The 26 test driving scenarios were presented twice to the subject, in 2 separated blocks. In the 4 subjects of each group, 2 subjects began with Block 1 and the other 2 began with Block 2, so there should be no between block (or between replicate) differences. The mean ratings for all scenarios of replicates 1 and 2 were 4.02 and 4.16, respectively, which were close. The 2 ratings were highly correlated (r=0.98) and the largest difference between any pair of ratings was 0.6, quite small considering workload was rated to the nearest 0.5. However, the pair-t test showed the significant difference on workload ratings (by scenario across subjects) between the 2 replicates (t(25)=2.61, p<0.05. Thus, there was a statistically significant difference, but not one that was practically significant.

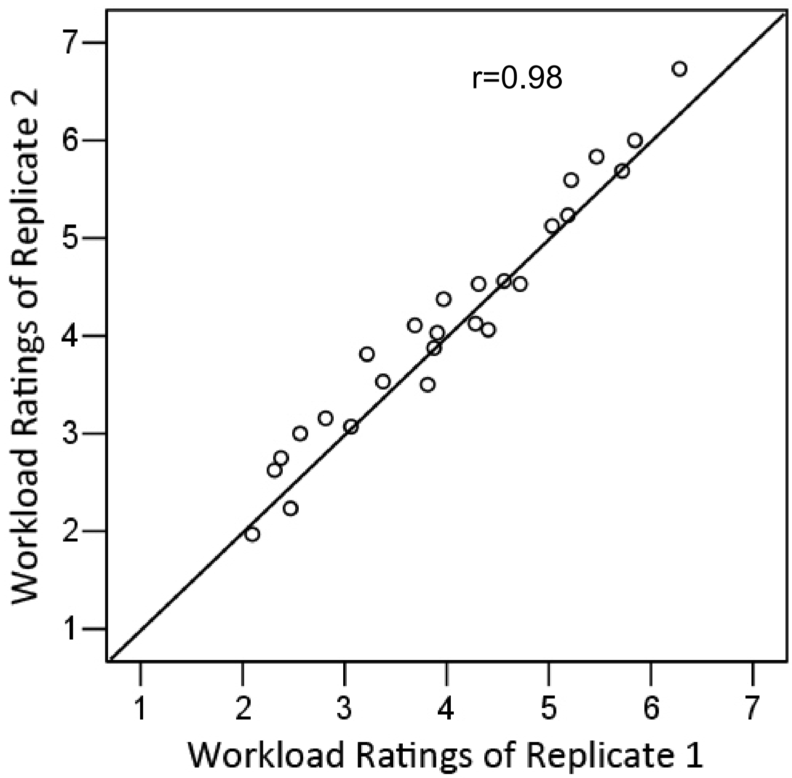


Figure 21. Workload Ratings of 2 Replicates

**The Comparisons of Workload Ratings When Driving in the Simulator and Watching Video Clips**

Side by side comparisons of video clips of 10 selected drives with video recordings of simulator duplications of them appeared to be very similar (r=0.84). However, the mean workload rating for 10 scenarios driven in the simulator was 4.3, and the mean rating for video clips of those same scenarios was less, 3.7. In fact, all of the scenarios except for 2 cases (Scenario 16, Driving: 4.4, Clips: 5.3 & Scenario 15, Driving: 3.0, Clips: 3.1) were rated as having greater workload when driven, an engagement effect (Figure 22). These 2 cases were special among the 10 scenarios, and subjects could have higher ratings for watching clips. Scenario 15 was the only 1 with a side vehicle passing subject vehicle by the left side with high speed. And scenario 16 was following a cement truck in the clip, which could not be created in the simulator. The rest of 8 scenarios had smoothly flowing traffic, and the rating difference between driving and watching clips was 0.9 (4.5 vs. 3.6), which became greater. Drivers were immersed in the driving task and interacted with the scenarios very much. Watching video brought less sense of driving so that subjects had lower workload. Another possibility was an order effect. For practical reasons, subjects always completed the driving task first, so the difference could reflect a decline in ratings with time (which should not occur as the ratings were with regard to fixed anchors).

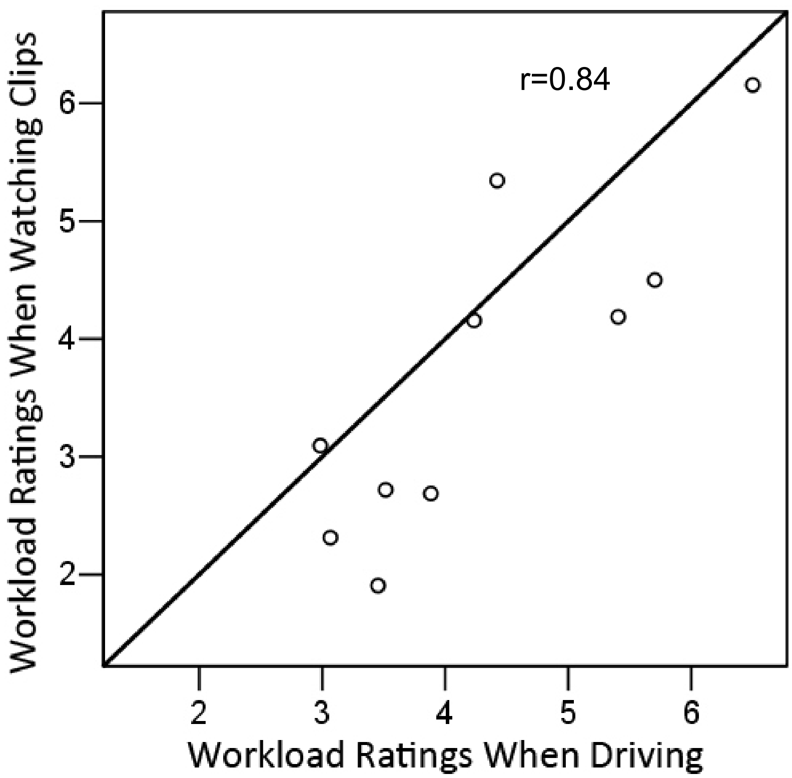


Figure 22. Workload Ratings When Driving and Watching Video Clips

It is important to note that minor differences between the clips and actual driving should lead to clips overestimating workload, not underestimating it. In the video clips, there was a mixture of cars and trucks, whereas in the analogs of them driven in the simulator, only cars were present, a limitation of the scenario development software. As an example of the implications of this difference, note how the pick up truck in the adjacent lane and the cement truck ahead in Figure 23 block the view of traffic, potentially increasing the workload.


Figure 23. A Frame from the Video for Scenario 16

In contrast to these findings, in the SAVE-IT (Schweitzer & Green, 2007) and previous M-CASTL project (Green, Lin, Schweitzer, Ho, and Stone, 2011), watching video clips led to greater workload ratings. This change may be the result of improvements in the instructions and anchor clips.

### Relationship between Traffic-related Factors and Workload Ratings

During each rating period, as is described later, several driving performance measures were collected, each at 60 Hz over 15 s (for a total of 900 data points), and statistics based on those 900 data points were used in regression equations to predict the workload ratings.

In this experiment, more than 70 statistics were calculated by the variables collected in the driving simulator. Sixty-six of them from 12 traffic-related factors were analyzed and used to build the workload prediction model, shown in Table 6. These factors could be categorized as when (1) subjects were interacting with other vehicles, (2) controlling their vehicle, and (3) other vehicles moved independently. Consistent with prior studies, to keep the data set manageable, only statistics whose correlation with the mean workload ratings (over subject by scenario) was 0.4 or greater were considered for further analysis. Using that criterion, there were 22 statistics from 7 traffic-related factors. To guide the regression analysis, distributions of each statistic and plots of each statistic against the mean workload ratings were examined.

Table 6. Summary of Mean Workload Rating Correlations While Driving
Note: Bold: |r|>0.4; numbers in () are for side vehicle 2

| Category | Traffic-related Factors | Statistics | r |
|---|---|---|---|
| Interactions With Other Vehicles | Lead Vehicle Gap | Mean | **-0.71** |
| | | Maximum | **-0.72** |
| | | Minimum | **-0.68** |
| | | Standard deviation | -0.21 |
| | | $Log_{10}$ (Mean) | **-0.75** |
| | Lead Vehicle Time-gap | Mean | **-0.73** |
| | | Maximum | **-0.74** |
| | | Minimum | **-0.69** |
| | | Standard deviation | -0.22 |
| | Traffic Count (with & without platoons) | Mean | **0.72, 0.73** |
| | | Maximum | **0.72, 0.73** |
| | | Minimum | **0.72, 0.73** |
| | Longitudinal Distances to Side Vehicles | Mean | **0.71** (0.31) |
| | | Maximum | **0.72** (0.27) |
| | | Minimum | **0.68** (0.35) |
| | | Standard deviation | 0.20 (-0.35) |
| Subject's Vehicle Longitudinal Control | Speed | Mean | 0.04 |
| | | Maximum | 0.09 |
| | | Minimum | -0.01 |
| | | Standard deviation | **0.41** |
| | Acceleration | Mean | -0.08 |
| | | Maximum | 0.12 |
| | | Minimum | -0.21 |
| | | Standard deviation | 0.39 |
| Subject's Vehicle Lateral Control | Lane Position | Mean | **0.58** |
| | | Maximum | **0.43** |
| | | Minimum | **0.74** |
| | | Standard deviation | **-0.66** |
| | Time-to-line Crossing | Mean | -0.06 |
| | | Maximum | -0.05 |
| | | Minimum | -0.03 |
| | | Standard deviation | 0.15 |

| | | | |
|---|---|---|---|
| Other Vehicles' Dynamics | Lead Vehicle Speed | Mean | -0.14 |
| | | Maximum | 0.05 |
| | | Minimum | -0.25 |
| | | Standard deviation | 0.30 |
| | Lead Vehicle Acceleration | Mean | 0.11 |
| | | Maximum | 0.25 |
| | | Minimum | -0.24 |
| | | Standard deviation | 0.34 |
| Other Vehicles' Dynamics | Side Vehicle Speed | Mean | -0.05 (-0.08) |
| | | Maximum | -0.11 (-0.07) |
| | | Minimum | -0.09 (-0.10) |
| | | Standard deviation | -0.02 (0.15) |
| | Side Vehicle Acceleration | Mean | -0.04 (-0.08) |
| | | Maximum | **-0.43** (-0.28) |
| | | Minimum | 0.25 (-0.16) |
| | | Standard deviation | -0.34 (-0.04) |

Interactions with Other Vehicles

1. Gap

Gap is the distance from the rear bumper of the lead vehicle to the front bumper of subjects' vehicle. The shorter the gap was, the greater the workload would be. In Figure 24, the correlations for mean, maximum, minimum, and standard deviation of gap to the mean workload ratings (over subjects by scenario) were -0.71, -0.72, -0.68, and -0.21. As in the SAVE-IT and previous M-CASTL project, the logarithm of gap, $\log_{10}$(gap) was more highly correlated with workload (-0.75) than gap alone. Drivers pay more attention to close vehicles ahead of them, but there is little difference to a vehicle that is far away or very far way, hence the log like function.

Further, keep in mind that in this experiment the gap varied over a limited range (few cases with extremely close or extremely distant lead vehicles), constraining the correlation.

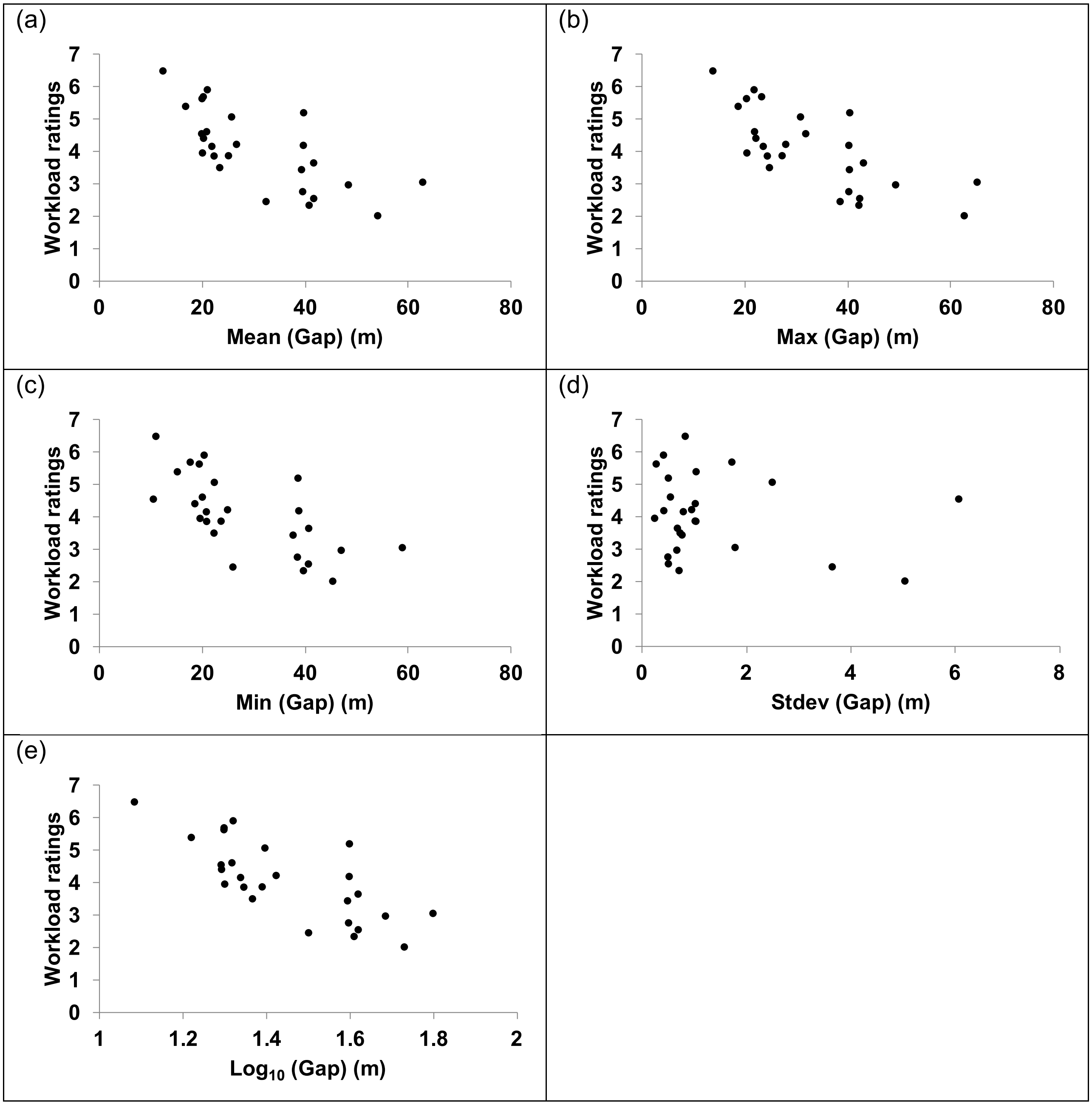


Figure 24. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Gap, (d) Its Standard Deviation, and (e) Logarithm of Gap

2. Time-gap

This is another measure to represent the distance to other vehicles. TTC has long been considered a factor that influences how people drive. In contrast to gap (distance), time gap also considers the subjects' speed. The distributions were shown in Figure 25 and correlations to workload ratings were also high, -0.73, -0.74, -0.69, -0.22 for mean, maximum, minimum, and standard deviation of time-gaps, respectively, very slightly greater than those for gap alone.  As the speed was over a limited range, 65 or 70 mi/hr, only a limited difference was expected between time and distance statistics.

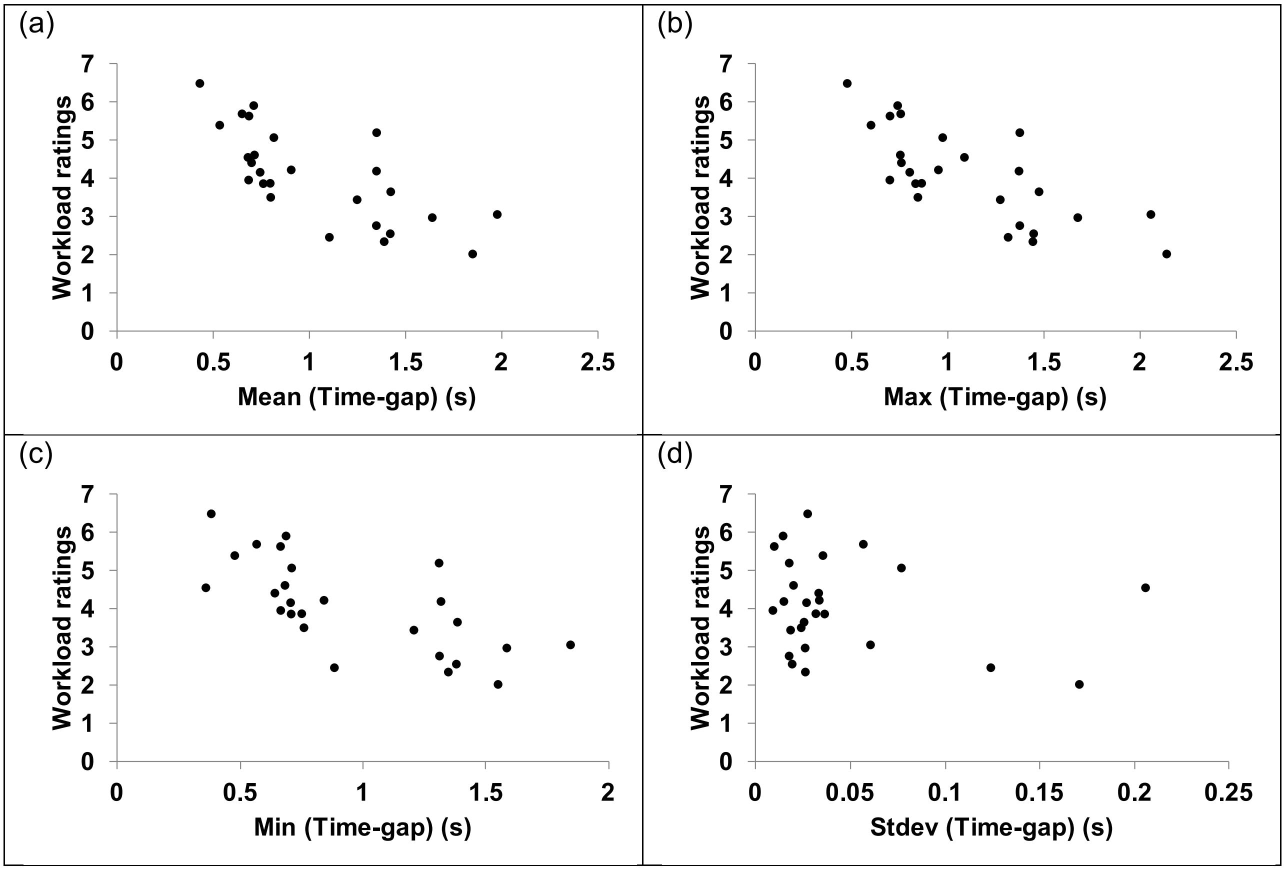


Figure 25. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Time-Gap, and (d) Its Standard Deviation

3. Longitudinal Distances to Side Vehicles

Side vehicles were always driving in the adjacent lanes and the 2 side vehicles would keep in the same lane.  Figure 26 shows the distance to side vehicle 1, which was always behind of side vehicle 2.  A negative distance indicates that side vehicles were driving adjacent to but behind the subject's vehicle.  Interestingly, the distance to side vehicle 1 had high positive correlations to workload (mean 0.71, maximum 0.72, minimum 0.68, standard deviation 0.20), and the ratings reached the highest when the distance was close to 0.  When the side vehicle drove side by side with subjects, there was more workload, and if the side vehicle passed, the workload would drop.  Thus, boxing the subject in added to workload.  Interestingly, the increase in workload per meter of added distance for the lead vehicle was comparable to those for paired vehicles in adjacent lanes.

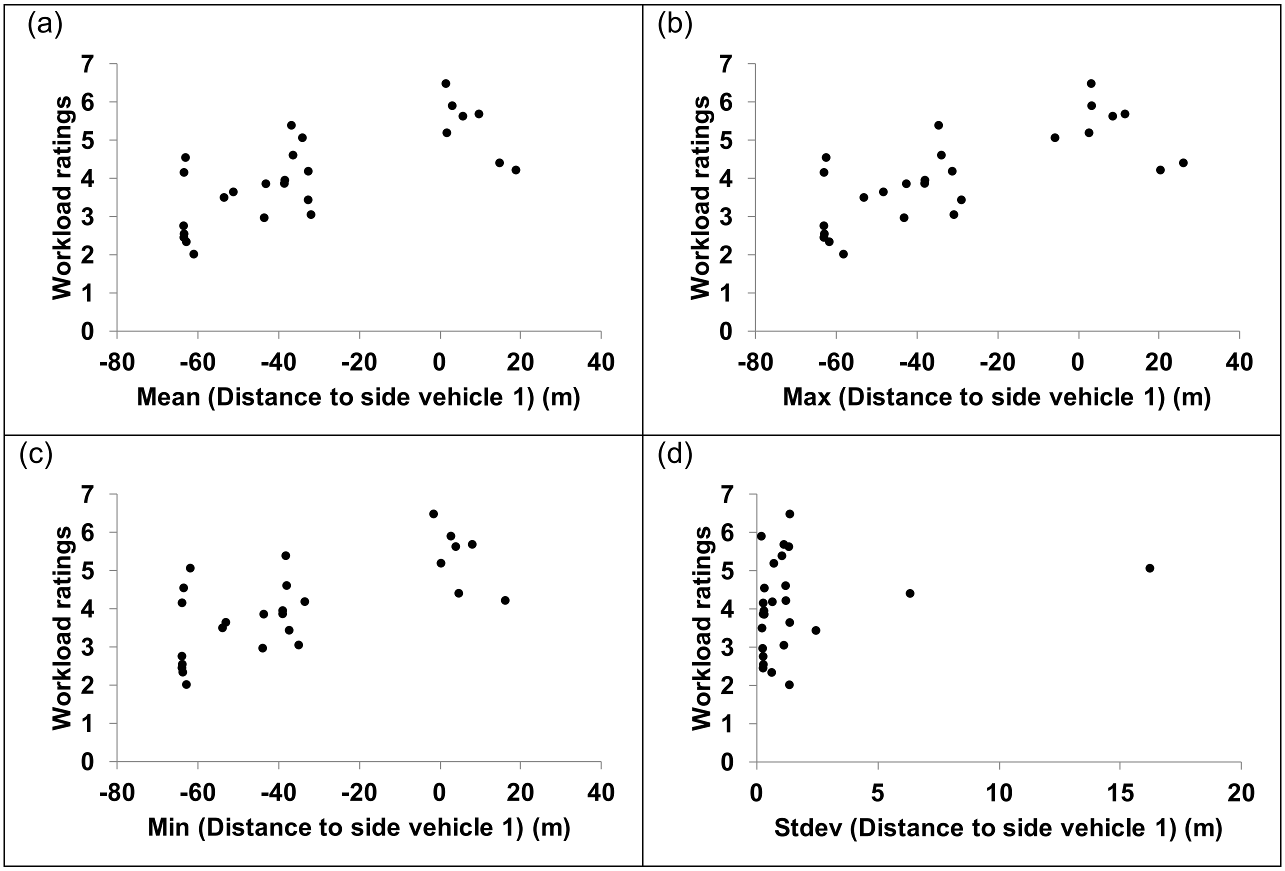


Figure 26. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Longitudinal Distance to Side Vehicle 1, and (d) Its Standard Deviation

Side vehicle 2 was always driving in front of side vehicle 1. The correlations of side vehicle 2 distances to the workload were lower than the side vehicle 1 because it usually drove ahead of subjects (max 0.31, maximum 0.27, minimum 0.35, standard deviation -0.35, as shown in Figure 27). The correlations remained low when the negative distances (driving behind the subject) were omitted. Vehicles ahead of the subject contribute more to workload than vehicles that are behind. Hence, the correlations were lower for side vehicles.

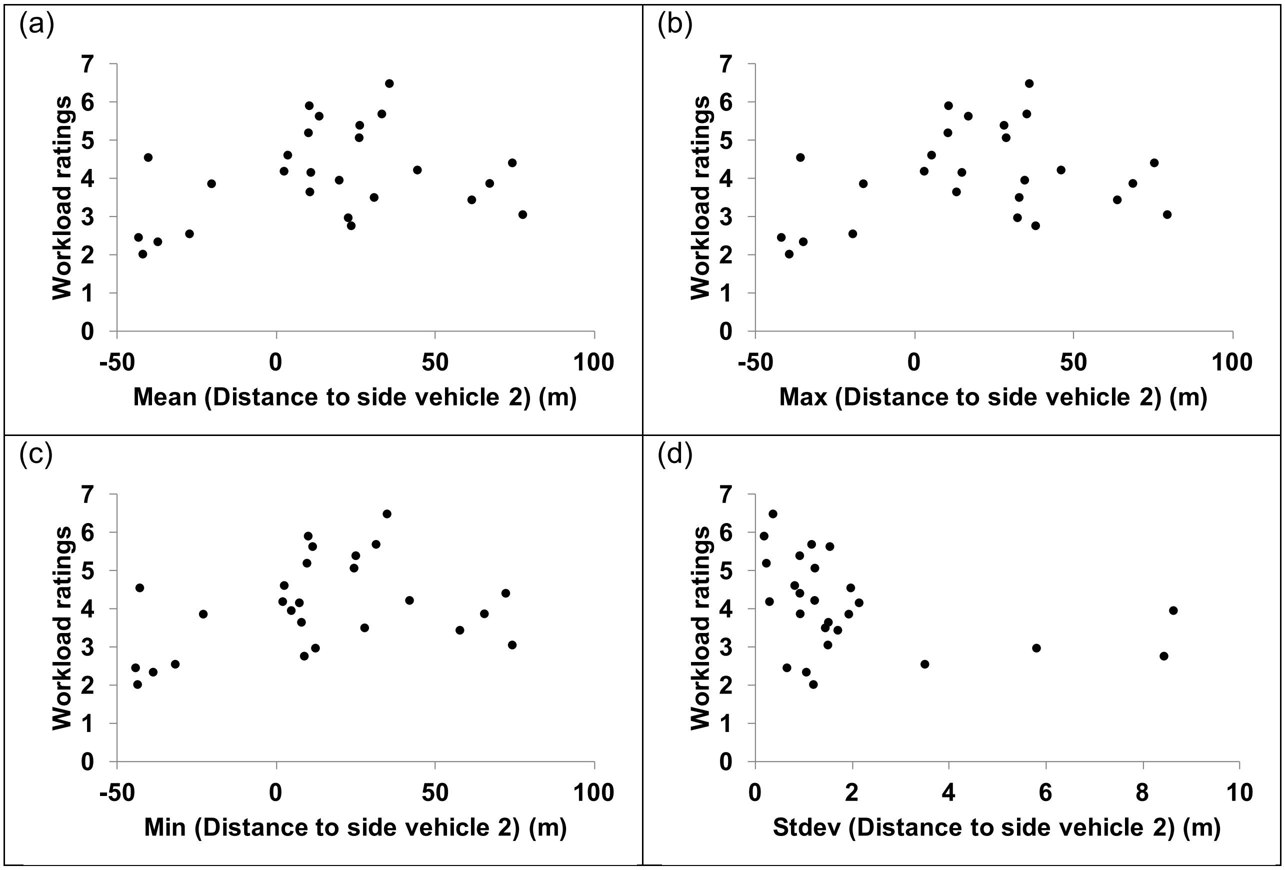


Figure 27. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Longitudinal Distance to Side Vehicle 2, and (d) Its Standard Deviation

4. Traffic Count

As long as a vehicle drove ahead of subjects' vehicle with the distance (rear bumper to subjects' front bumper) of 0-125 m, it would be counted as the traffic. In all scenarios, traffic counts were between 1 (lead vehicle only) and 5 (1 lead vehicle + 2 side vehicles + 2 platoon vehicles). In fact, there were 3 cars as the platoon, but the lead vehicle was always blocked by 1 of the 3, so that subjects could not see it. The standard deviation was not analyzed because most scenarios had stable traffic flow, which had the traffic count standard deviation as 0. The traffic count was highly correlated with the workload ratings, with the coefficients of 0.72 for mean, maximum, and minimum (see Figure 28). Furthermore, if the effects of platoon were removed (traffic counts became 1-3), the correlations were similar (0.73 for mean, maximum, and minimum traffic count).

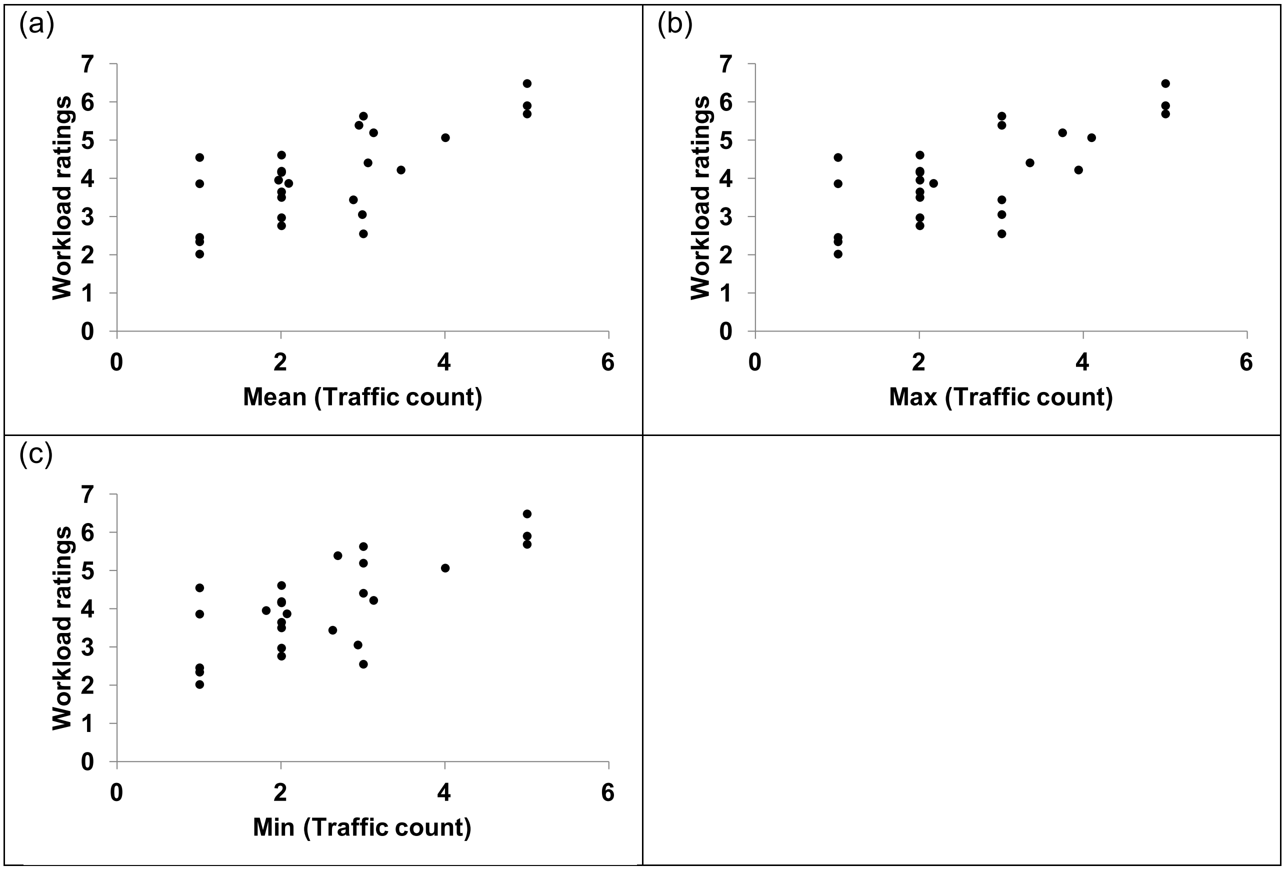


Figure 28. Workload Ratings While Driving:
(a) Mean, (b) Maximum, (c) Minimum Traffic Count

Subject's Vehicle Longitudinal Control

In this category, factors influencing how well subjects drove in the simulator were considered, both longitudinally and laterally. One could make the argument that poor longitudinal control (e.g., greater standard deviation of speed) should be indicative of higher workload, and for any fixed set of conditions, lower speed. Again, the range of speeds was limited, so speed effects seemed unlikely.

1. Speed

For all 26 scenarios, subjects were requested to drive at 65 mph (28.9 m/s) and 70 mph (31.1 m/s), depending on the scenario, reflected in the grouping shown in Figures 29a, b, and c. Therefore, correlations of speed factor with workload were low: mean 0.04, maximum 0.09, and minimum -0.01. However, the standard deviation of speed had something to do with the workload, with the correlation of 0.41. Again, difficulty in controlling speed may indicate greater workload. In the real world, that workload can come from instability of the traffic stream.

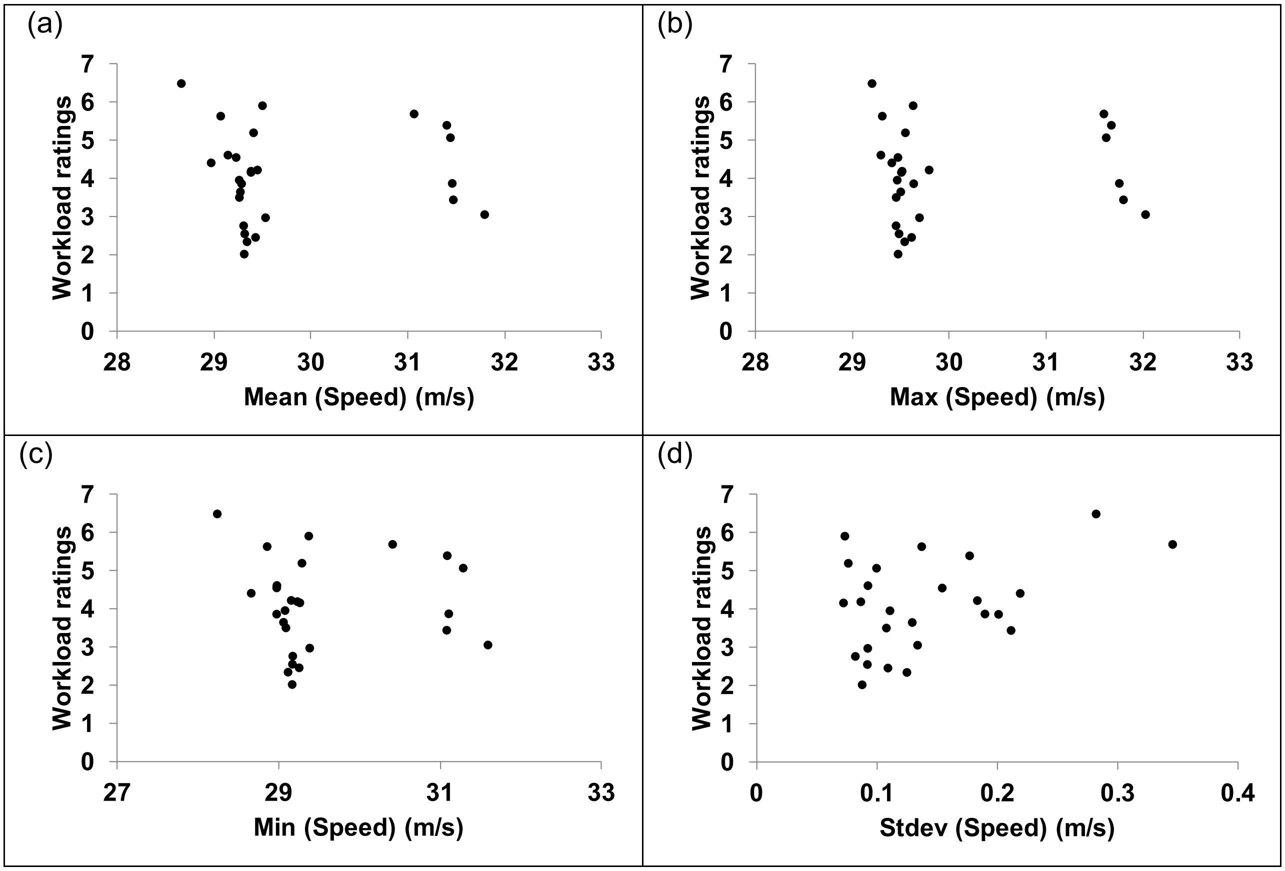


Figure 29. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Speed, and (d) Its Standard Deviation

2. Acceleration and Deceleration

Similar to the speed, variations in acceleration were small because the subject's speed was fixed so the scenarios to be rated would be stable. The correlations of mean, maximum, and minimum accelerations to workload were -0.08, 0.12, -0.21, respectively. The standard deviation of acceleration (Figure 30) had the correlation of 0.39, which represented that the changes of acceleration could increase drivers' workload. The situation could be different in real world driving where that experimental constraint, the need to reduce experimental variance, would not be present.

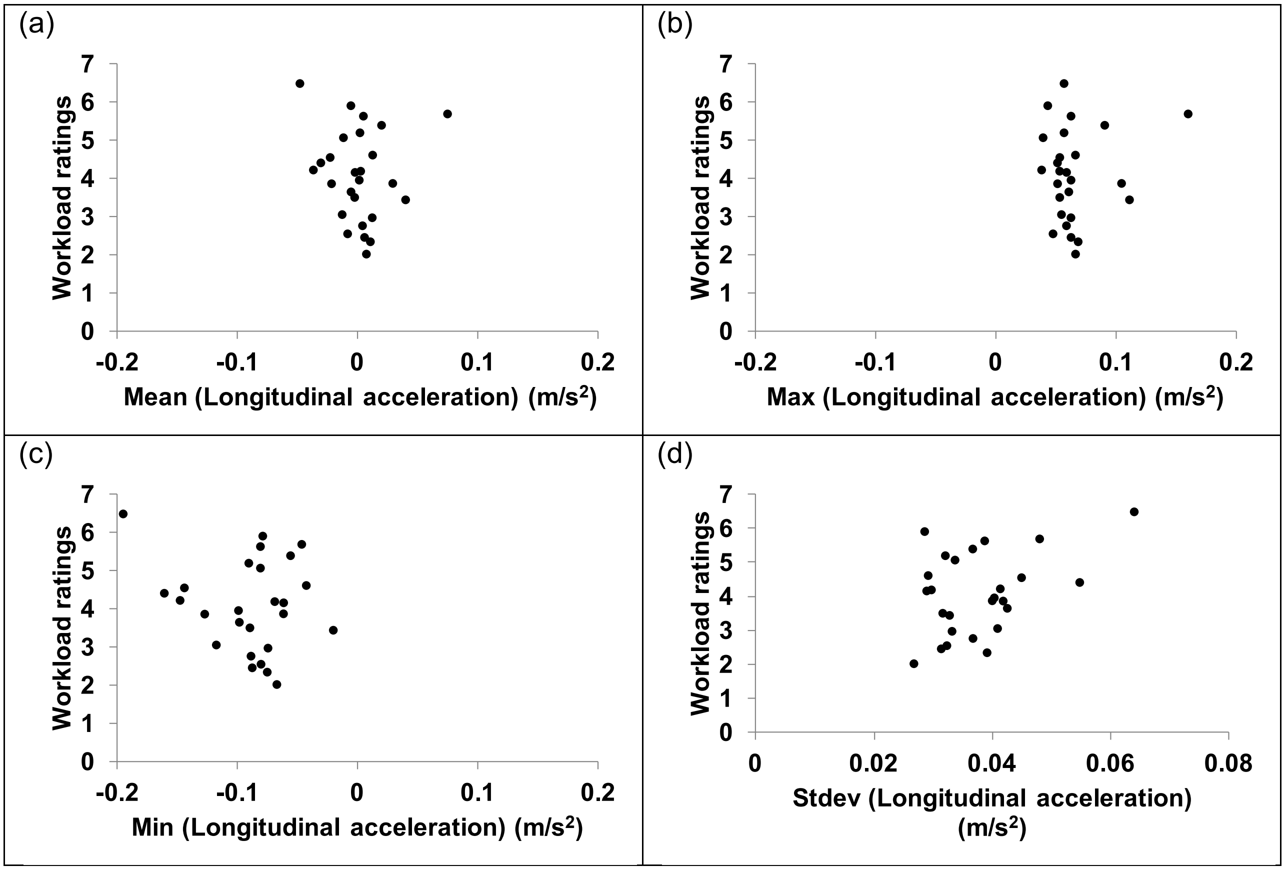


Figure 30. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Longitudinal Acceleration and (d) Its Standard Deviation

<u>Subject's Vehicle Lateral Control</u>

1. Lane Position
For this measure, a negative value was to the left of the lane center, and positive value was to the right. On average, subjects drove in right half of the lane and sometimes approached the lane boundary (Figure 31). The correlations of mean, maximum, minimum, and standard deviation lane position to workload were 0.58, 0.43, 0.74, and -0.66, respectively. This has been found in previous studies (Green, Kang, Alter, Best, & Lin, 2011), where subjects want to increase the lateral gap between them and other vehicles. In this experiment, side vehicles were always to the left of the subject when the subject was driving in the right and middle lane, and there was always an open lane or wide shoulder (with no barrier) to the right. So, if side vehicles approached, there was no apparent risk of driving a bit too far to the right. For cases of driving in the left lane, the mean, maximum, and minimum lane position were 0.24 m, 0.6 m, -0.1 m. Subjects still drove in the right half of the lane because the left shoulder was narrow.

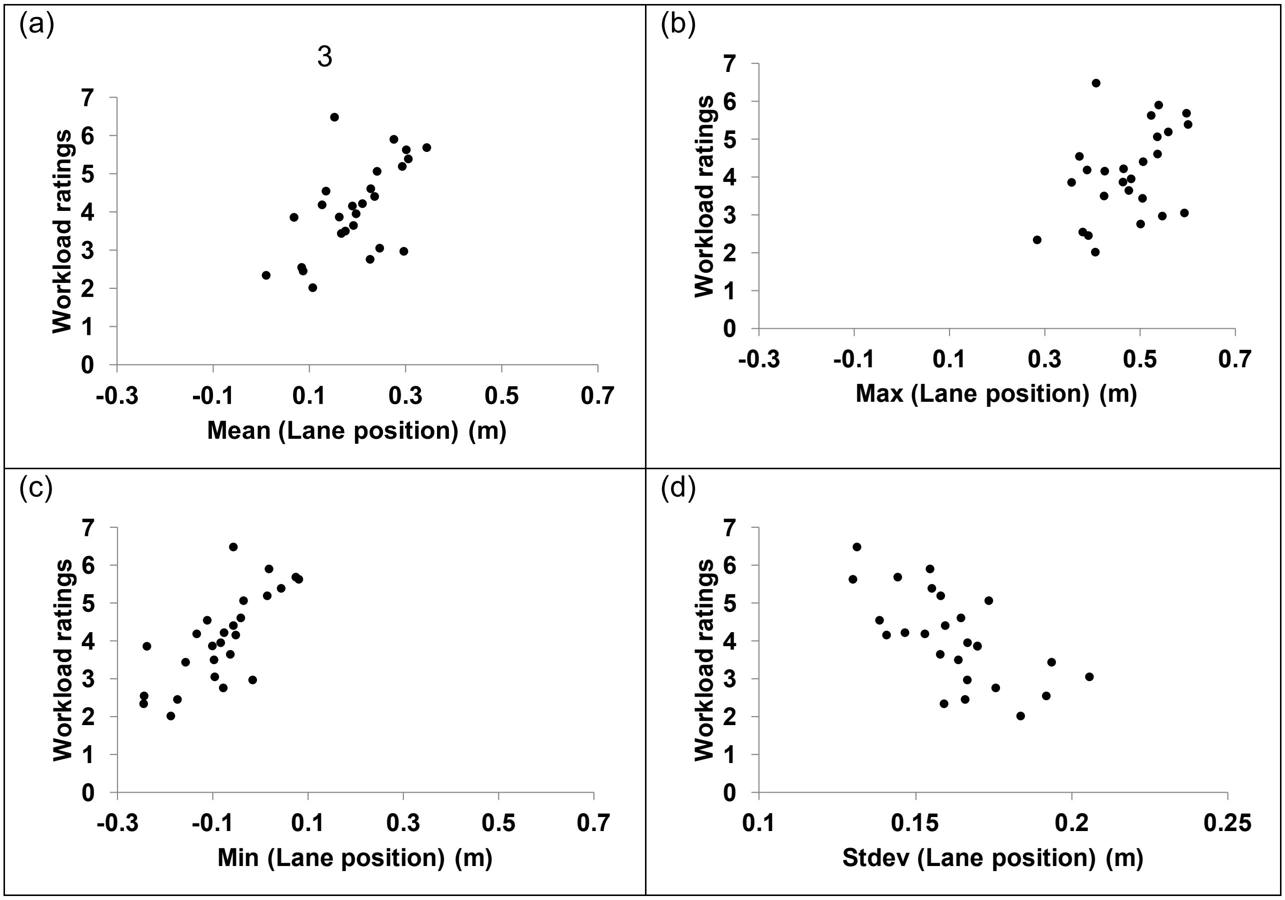


Figure 31. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Lateral Lane Position, and (d) Its Standard Deviation

2. Time-to-line Crossing (TLC)
This measure has typically been useful for the study of distraction. However, in this experiment, the road was straight, there were no cross winds, the vehicle did not induce lateral drift (due to uneven tire pressures), and drivers never changed lanes, so maintaining lateral control was easy. Thus, TLC was consistently long and the minimum TLC was greater than 2 s (as shown in Figure 32). Given the limited range of TLC, the correlations of TLC with mean workload were quite low, mean -0.06, maximum -0.05, minimum -0.03, and standard deviation 0.15. The situation could be different if lateral position was difficult to maintain.

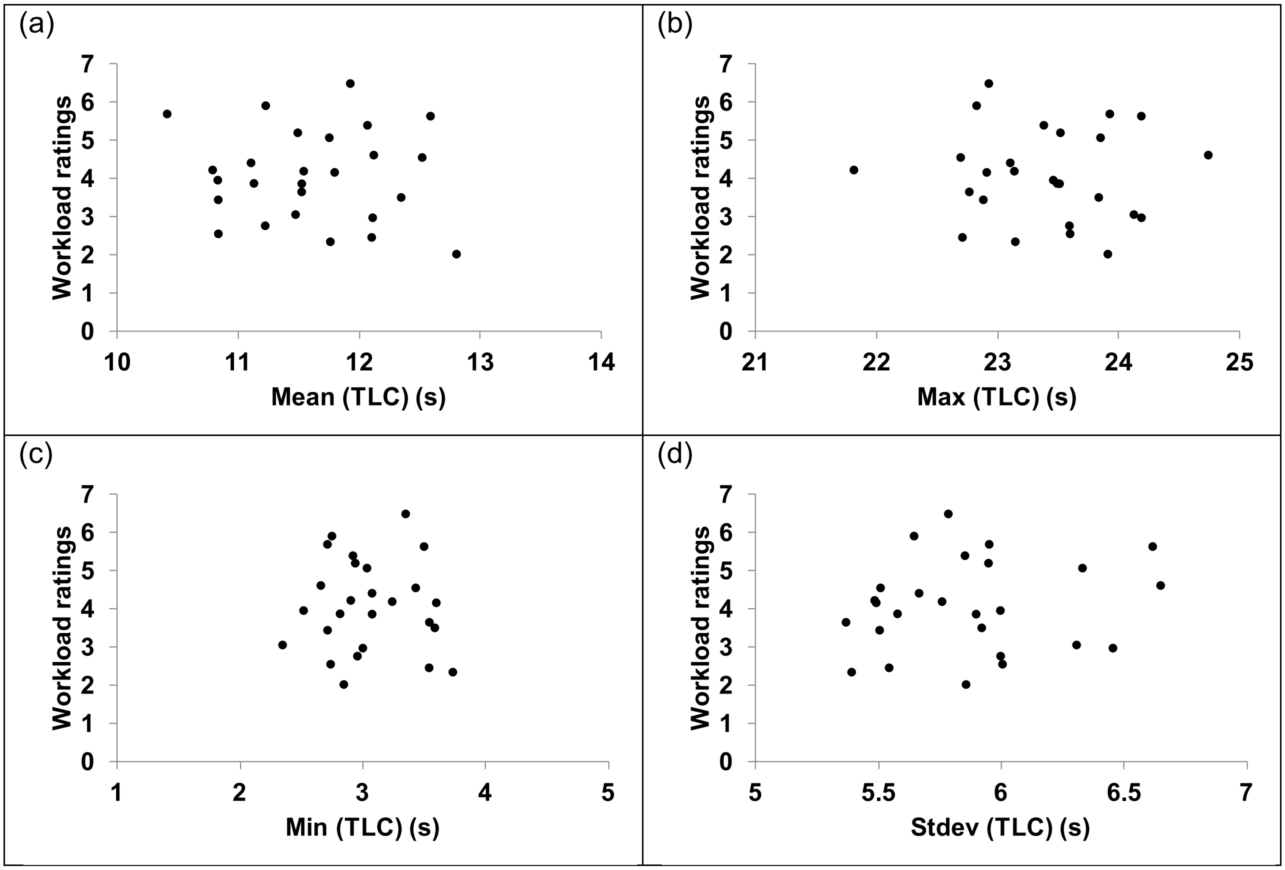


Figure 32. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum TLC, and (d) Its Standard Deviation

Lead Vehicle' Dynamics

1. Speed

In the design of experiment, the lead vehicle speed did not change often, usually matching the subject vehicle's speed. Therefore, it slightly correlated to workload, with the coefficients of -0.14, 0.05, -0.25, and 0.30 for mean, maximum, minimum, and standard deviation.

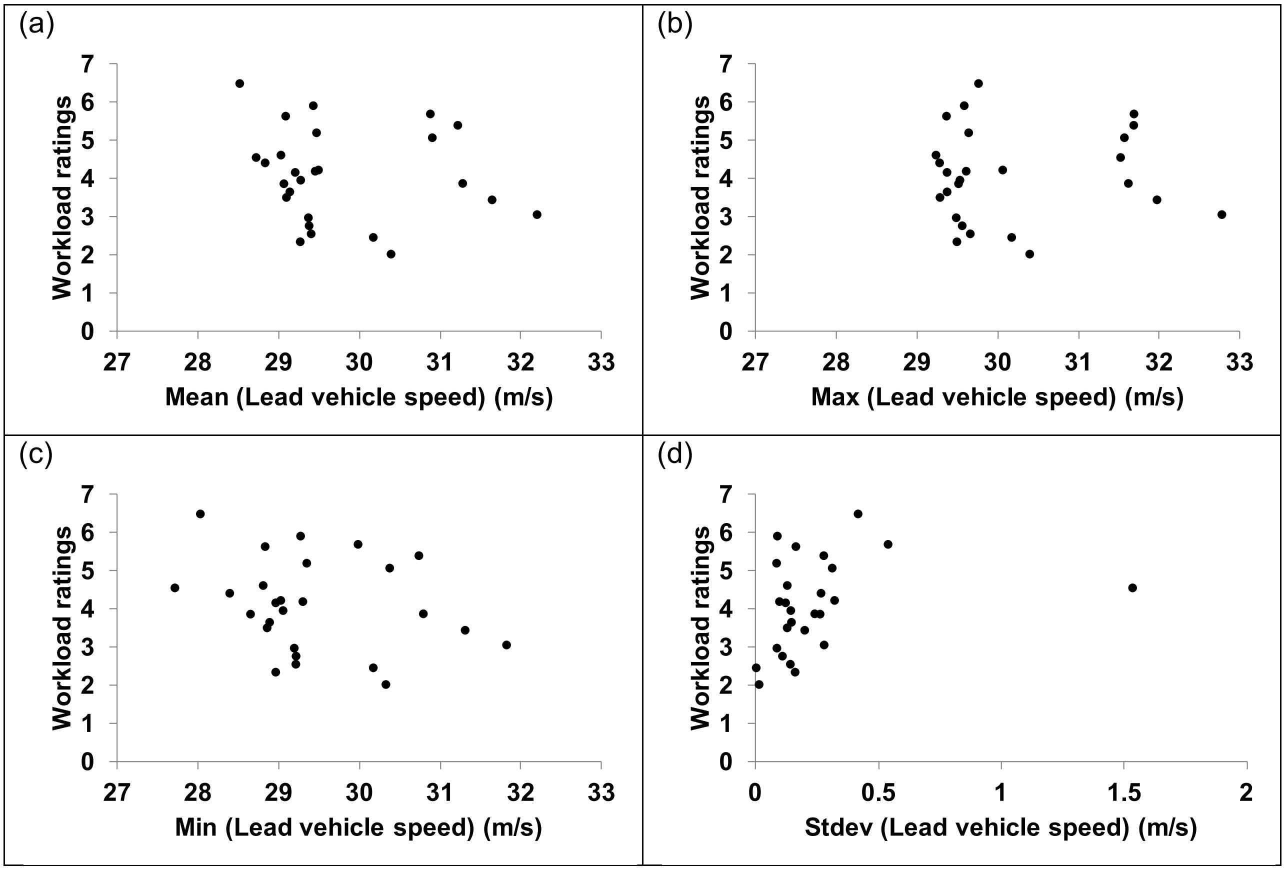


Figure 33. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Lead Vehicle Speed, and (d) Its Standard Deviation

2. Acceleration
As lead vehicle acceleration was fixed in this experiment, except for random variation, it should have no effect. That proved to be the case. The correlations were not high, with a mean of 0.11, a maximum of 0.25, a minimum of -0.24, and a standard deviation of 0.34. (See Figure 34.)

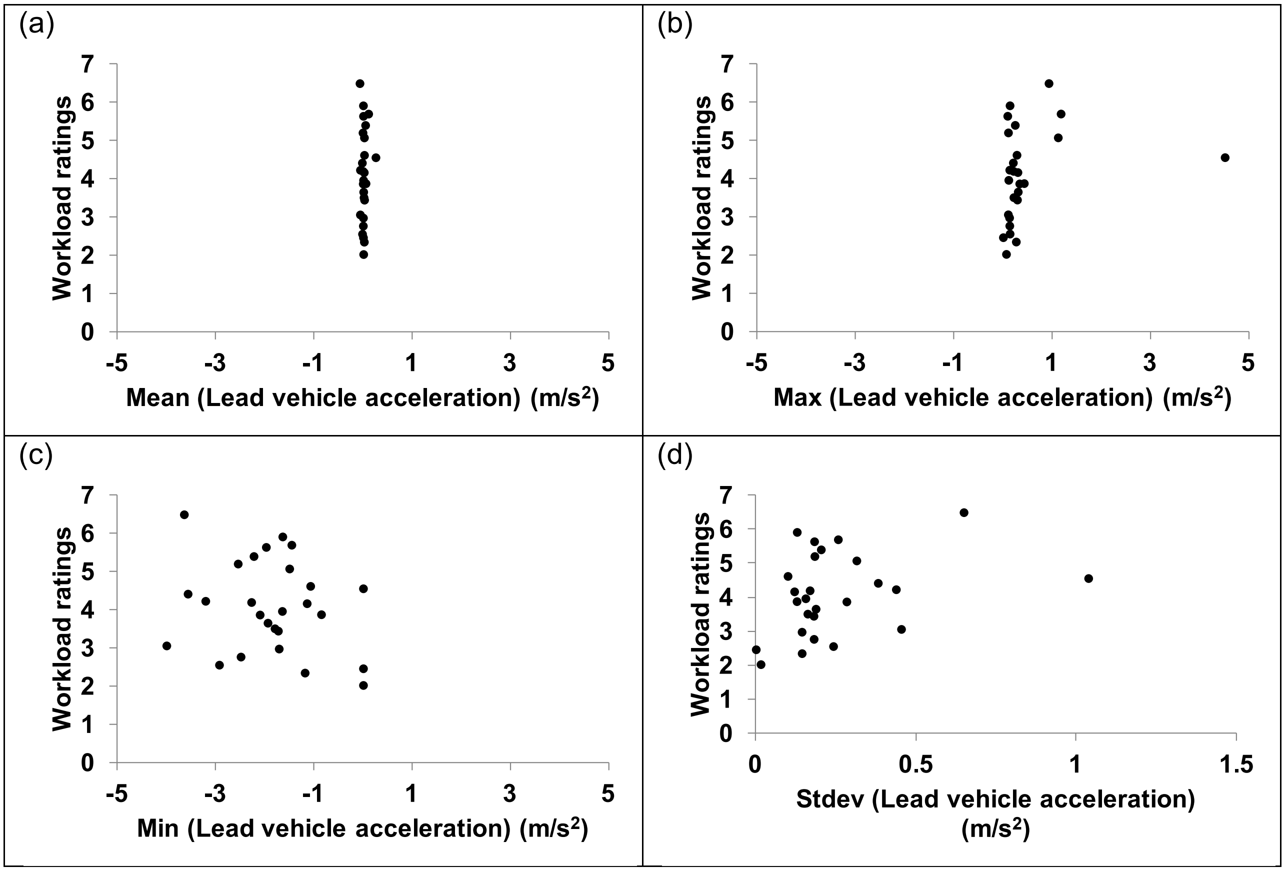


Figure 34. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Lead Vehicle Acceleration, and (d) Its Standard Deviation

Side Vehicles' Dynamics

1. Speed

Figures 35 and 36 show the distributions of the speeds of side vehicles 1 and 2. Actually, subjects were more concerned about the locations of side vehicles than their speeds. The correlations were quite low that mean, minimum, maximum and the standard deviation of the speed of side vehicle 1 (side vehicle 2) with workload ratings were -0.05 (-0.08), -0.11 (-0.07), -0.09 (-0.10), and -0.02 (0.15). The workload of vehicles approaching the subject was greater than for vehicles that were pulling away.

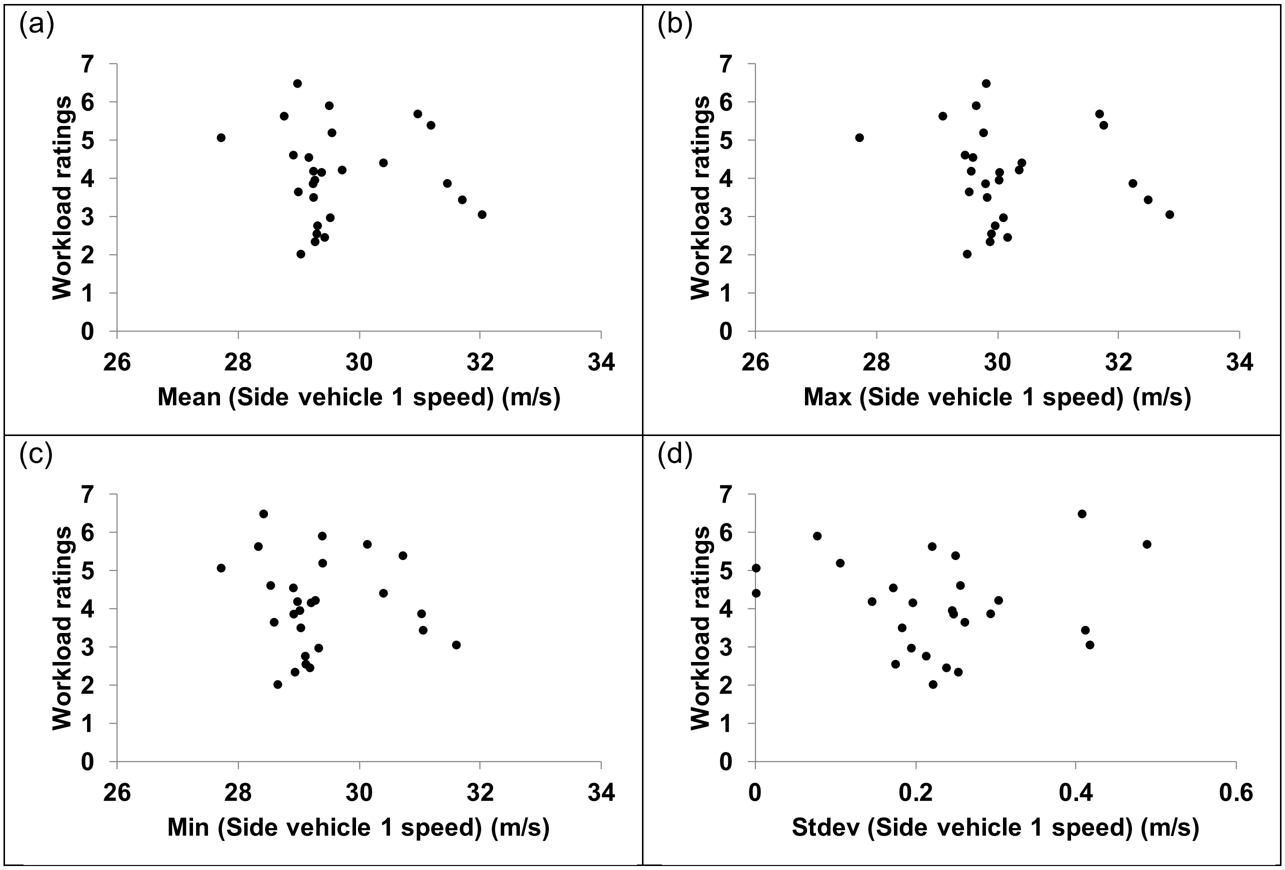


Figure 35. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Speed of Side Vehicle 1, and (d) Its Standard Deviation

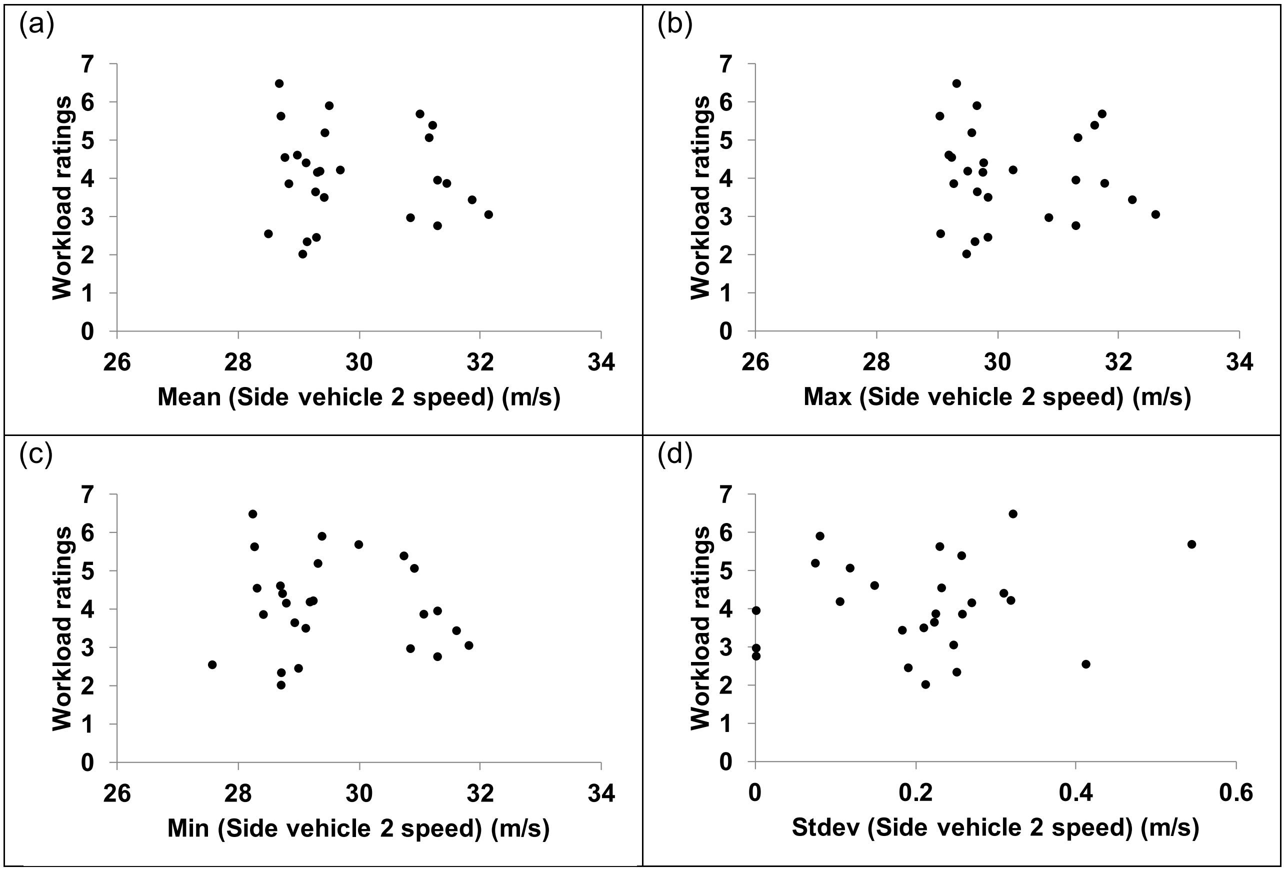


Figure 36. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Speed of Side Vehicle 2, and (d) Its Standard Deviation

2. Acceleration

Figures 37 and 38 show the distribution of side vehicles' acceleration. Side vehicle 1 would have higher influences than side vehicle 2 because it was closer to subject vehicle. Correlation coefficients of side 1 (side 2) were -0.04 (-0.08), -0.43 (-0.28), 0.25 (-0.16), and -0.34 (-0.04) of mean, maximum, minimum, and standard deviation of accelerations. When side vehicle 1 sped up (and maximum acceleration increased), subjects could sense that it was going to pass from behind, which led to greater workload. Keep in mind that the number of alternative values of side vehicle acceleration considered were limited.

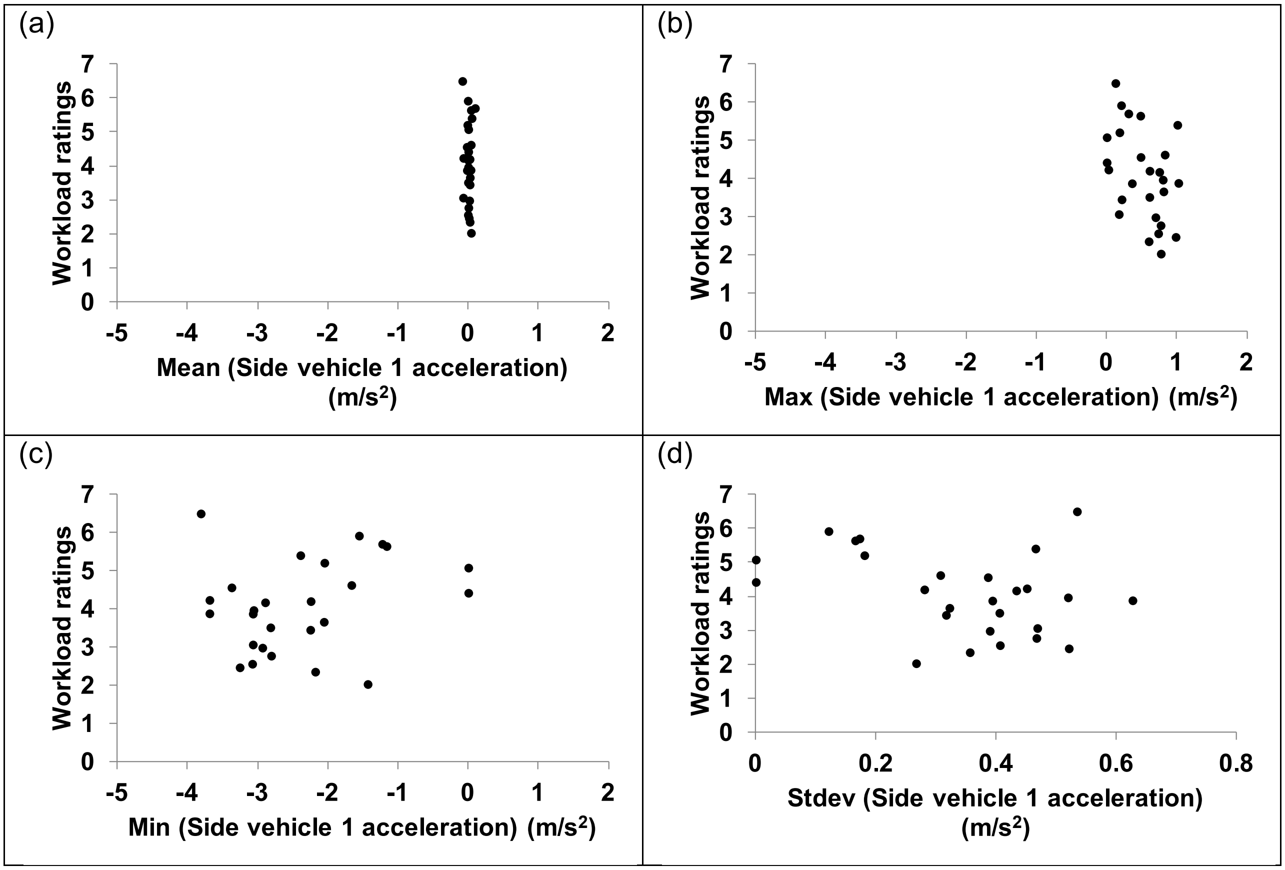


Figure 37. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Acceleration of Side Vehicle 1, and (d) Its Standard Deviation

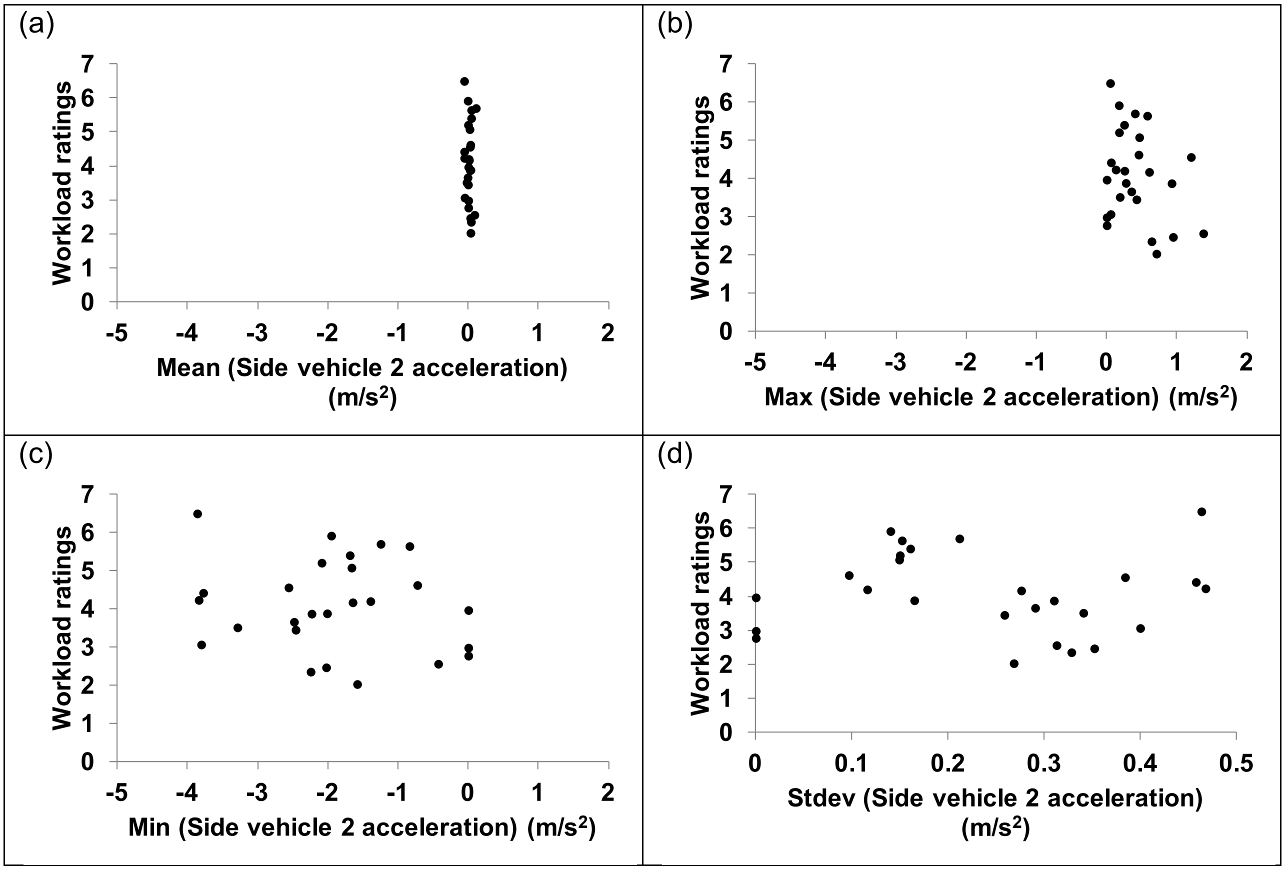


Figure 38. Workload Ratings While Driving: (a) Mean, (b) Maximum, (c) Minimum Acceleration of Side Vehicle 2, and (d) Its Standard Deviation

## Equations to Estimate Workload Ratings

This experiment included side vehicles, and they contributed to the workload. Table 7 shows the workload estimation equations from this study. Two methods were used, stepwise regression with all variables, and entering with the gap of side vehicle 1 (behind of side vehicle 2). As shown in Table 7, the $\log_{10}$(gap), mean traffic count, drivers' lateral lane position, and vehicle 1 gap were the factors in the equation to predict workload. For the vehicle 1 gap, the minimum, mean, or maximum were similarly predictive. The $R^2$ for the best fitting equation was remarkably high, 0.89.

Table 7. Workload Equations of This Study

| Methods | # Factors | Equations | $R^2$ |
|---|---|---|---|
| Stepwise with all variables | 2 | 8.33<br>-3.83*LogGap<br>+0.49*MeanTrafficCount | 0.80 |
| | 3 | 8.38<br>-3.33*LogGap<br>+0.33*MeanTrafficCount<br>+4.25*MinimumLanePosition | 0.86 |
| | 4 | 8.53<br>-3.18*LogGap<br>+0.28*MeanTrafficCount<br>+4.70*MinimumLanePosition<br>-0.10*StDevSideVehicle2Gap | 0.89 |
| Entering with side vehicle 1 gap | 4 | 8.66<br>-3.19*LogGap<br>+0.23*MeanTrafficCount<br>+3.92*MinimumLanePosition<br>+0.01*MeanSideVehicle1Gap | 0.87 |
| | 4 | 8.66<br>-3.18*LogGap<br>+0.23*MeanTrafficCount<br>+3.94*MinimumLanePosition<br>+0.01*MaximumSideVehicle1Gap | 0.87 |
| | 4 | 8.60<br>-3.20*LogGap<br>+0.26*MeanTrafficCount<br>+3.95*MinimumLanePosition<br>+0.01*MinimumSideVehicle1Gap | 0.87 |

The results from this experiment, SAVE-IT, and the previous M-CASTL project were compared in 2 different ways, the best fitting stepwise equations, and equations with the same factors. Again, the stepwise analysis of the data from this experiment considered factors related to side vehicles position and movement, factors that were not explicitly considered in previous studies. In the resulting equations for the current experiment, subjects' lane position and side vehicle gap replaced the acceleration of subject and lead vehicle (shown in Table 8). Table 8 shows the workload estimation equations from SAVE-IT, previous M-CASTL project, and this study, determined by forcing the <u>same</u> independent variables into the regression equation. What is remarkable is the very high percentage of the regression variance accounted for (just under 80 % in this case), and the extremely consistent regression coefficients values, especially between the SAVE-IT study and this one. Keep in mind that for this experiment, independent variables were included in the experiment that were not present previously, constraining the $R^2$ values if only the previous independent variables are included in the equation.

Table 8. Equations from SAVE-IT, M-CASTL-1, and This Study with Same Factors

| # Factors | Variables | Coefficients | | |
|---|---|---|---|---|
| | | SAVE-IT | M-CASTL-1 | This Study |
| 2 | Constant | 8.86 | 7.90 | 8.27 |
| | LogMeanGap | -3.00 | -2.52 | -3.78 |
| | MeanTrafficCount | 0.47 | 0.06 | 0.50 |
| | $R^2$ | 0.82 | 0.69 | 0.79 |
| 3 | Constant | 8.87 | 7.90 | 8.28 |
| | LogMeanGap | -3.01 | -2.51 | -3.79 |
| | MeanTrafficCount | 0.48 | 0.06 | 0.50 |
| | MeanLongitudinalAcceleration | 2.05 | 0.51 | 0.34 |
| | $R^2$ | 0.87 | 0.69 | 0.79 |
| 4 | Constant | 8.07 | 8.57 | 8.18 |
| | LogMeanGap | -2.72 | -2.72 | -3.71 |
| | MeanTrafficCount | 0.48 | 0.13 | 0.53 |
| | MeanLongitudinalAcceleration | 2.17 | -14.28 | -0.60 |
| | MinimumLeadVehicleAcceleration | -0.34 | 0.20 | 0.05 |
| | $R^2$ | 0.85 | 0.74 | 0.79 |

# EXPERIMENT 2: IMPROVEMENT OF ANCHOR CLIPS - ISSUES AND METHOD

## Issues and Approach

All but 1 of the project issues were examined in the first experiment, namely part of issue 2 that concerned improving the image quality and content representation of the anchor clips. As the prior experiment had led to improved image quality, this experiment addressed content.

For practical reasons, the display showing the anchor clips needs to be large, close to the line of sight, and as large as possible so objects of interest such as other vehicles are easy to see. Furthermore, for ease of packaging reasons, there should only be a single display for each anchor and it should be rectangular. The choice of a single display not only has implications for this experiment, but for other situations where representing the entire driving situation in a single display is advantageous, such as in an armored vehicle. Thus, the focus of the second experiment was to determine how information about the driving scene could be presented to optimize situation awareness.

Specifically, this experiment concerned the content of the anchor clips.

1. How should information about the rear scene be presented, as a single, wide field of view mirror or 3 separate mirrors as is the case now?
2. What is the tradeoff between making objects directly ahead larger and making the field of view wider?
3. Does the preferred mirror configuration depend upon the number of nearby vehicles, either to the front or the rear?

To make decisions about which representation of the road scene was best, subjects needed to be able to see all alternatives at the same time, but the size and visual angle of the displays needed to be close to what subjects would see in the test vehicle or simulator. Visual angle is important because it determines how easy objects in the scene are to see, especially objects in mirrors. Therefore, the experimental approach selected was to use a printout of the road scene on paper that could be sorted on a large table, with the printout being the same size as the images used in the previous experiment.

## Displays Shown to Subjects

Five sets of 9 displays were created using Virtools Dev 3.0 (virtual reality engine, to integrate 3D models) and 3ds Max 5.0 (3D modeling software, to create 3D models). There was a practice set of images showing 4 cars, and test sets showing 2, 5, 8, and 11 cars. The subject’s vehicle was always in the middle lane. Figure 39 shows an example of 8 cars. Table 9 shows where the vehicles were located for each set. Ideally, there would have been more combinations of locations and the number of vehicles, but the project schedule and resources did not accommodate such and are left to future studies.

Figure 39. Example Road Scene Image

Table 9. Distance of Other Cars from the Subject in Car Lengths
(1 Car Length = 5 m)

| Location of Other Cars | Number of Cars Shown | | | | |
|---|---|---|---|---|---|
| | 4 (Training) | 2 | 5 | 8 | 11 |
| Front | 2 | 3 | 3 | 2 | 1 |
| Left front | — | — | 2 | 2 | 3 |
| Left side front | — | — | — | Overlap | 0 |
| Right front | — | — | 1 | 3 | 2 |
| Right side front | Overlap† | — | — | — | 0 |
| Behind | 2 | — | 1 | 3 | 2 |
| Left behind | 1 | — | 2 | 1 | 2 |
| Left side behind | — | — | — | — | 0 |
| Left far behind | — | — | — | — | 4 |
| Right behind | — | 2 | — | 2 | 1 |
| Right side behind | — | — | — | 0‡ | Overlap |

† Overlap: The car in the adjacent lane had longitudinal overlap with subject vehicle.
‡ "0": The car in the adjacent lane was just in the front or back of subject vehicle.

Within each combination, the field of view and how the rear scene was represented varied (Table 10). There was some discussion of including a 90-degree field of view image, but that image cut off too much of the adjacent lanes, completely omitting nearby vehicles in adjacent lanes that could cut in to the subjects' lanes. Fields of view much wider than 180 degrees are unlikely to be useful, as parts of vehicles in blind spots are visible with that field of view. Thus, there were 36 images (3 mirror configurations, 4 traffic counts, & 3 field of views) to consider.

Table 10. Image Combinations Shown

| Field of View | Rear Scene Representation | | |
|---|---|---|---|
| | No Mirrors | 3 Mirrors | 1 Wide Field of View Mirror |
| 120 | x | x | x |
| 150 | x | x | x |
| 180 | x | x | x |

The choice of 3 fields of view simplified the experiment. The no mirror condition was included as a baseline, and the single, wide field of view mirror as an alternative to the existing mirror configuration. There are numerous alternatives to current mirrors—larger magnifying mirrors, video monitors in place of mirror mounted closer inboard, video monitors on top of the dash (so the driver could continue to look ahead), etc. (Alter, Lo, and Green, 2007; Green, Alter, Schweitzer, Walls, and Lin, 2007). There are many options. Consideration of them was left to a future study.

## Test Sequence

Table 11 shows the subject tasks and their durations. The most important task that subjects performed was to rank order the images in terms of how well they made subjects aware of the surrounding traffic, bearing in mind that all vehicles around them were not equally important. However, saying too much in the instructions about this would be leading the subjects to conclusions the experimenters had made.

Table 11. Task Sequence and Durations

| # | Task | Duration (min) |
|---|---|---|
| 1 | Introduction – consent form (Appendix H), biographical information (Appendix I), instructions, vision check | 15 |
| 2 | Practice driving the rating task | 10 |
| 3 | Recall vehicle locations and rank 4 sets of images | 15-20 |
| 4 | Post test (Appendix J) | 10 |
| 5 | Pay subject $25 and sign payment form | 2 |
| Total | | 52-57 |

Thus, it was desired for subjects to use the displays during the experiment for some purpose related to situation awareness before ranking the displays from best to worst in that regard. The situation awareness literature (Endsley, 1995a, b; Gugerty, 1997; Endsley and Garland, 2000) refers to 3 levels of awareness (1) perception-detection objects in the environment, (2) understanding-determining the impact on the user's goals and objectives, and (3) projection-making predictions in the future. In driving, what is more important is a combination of levels 2 and 3—being able to predict (1) which vehicles are the greatest threat to the driver and (2) where they will be in the future. However, being able to make such decisions could require a dynamic display, a video loop showing vehicle movement, which was beyond the resources of this project. Thus, the focus was on level 1, asking subjects to recall where vehicles were in the scenes.

Specifically, for the test of locating vehicles, 36 scenes were shown to subjects in 3 groups, with each group representing a particular field of view (120°, 150°, & 180°). Twelve images (3 mirror configurations x 4 traffic counts) of 1 field view were shown to subjects to mark locations of vehicles. Subjects were equally split into the 3 groups with a specific field of view. Within groups, the order of mirror conditions was different for each group. Appendix K describes the order of images that subjects saw.

Next, using a form containing the Figure 40, subjects recalled the location of each vehicle in the scene, using a C to indicate the location of a car and a T for a pick-up truck. Admittedly, this made all vehicles equally important regardless of their threat to the subject.

After marking the locations of vehicles in 12 images, subjects were requested to rank the configurations in the same traffic counts (2, 5, 8, or 11) in order, which included 9 scenes in a set. Over 4 sets, subjects could finish this experiment and enter the post-test evaluation phase.

In the conference room, where the experiment took place, all materials were laid out on the table (8 ft x 4 ft). Figure 41 shows the example when subjects were ranking 9 scenes.

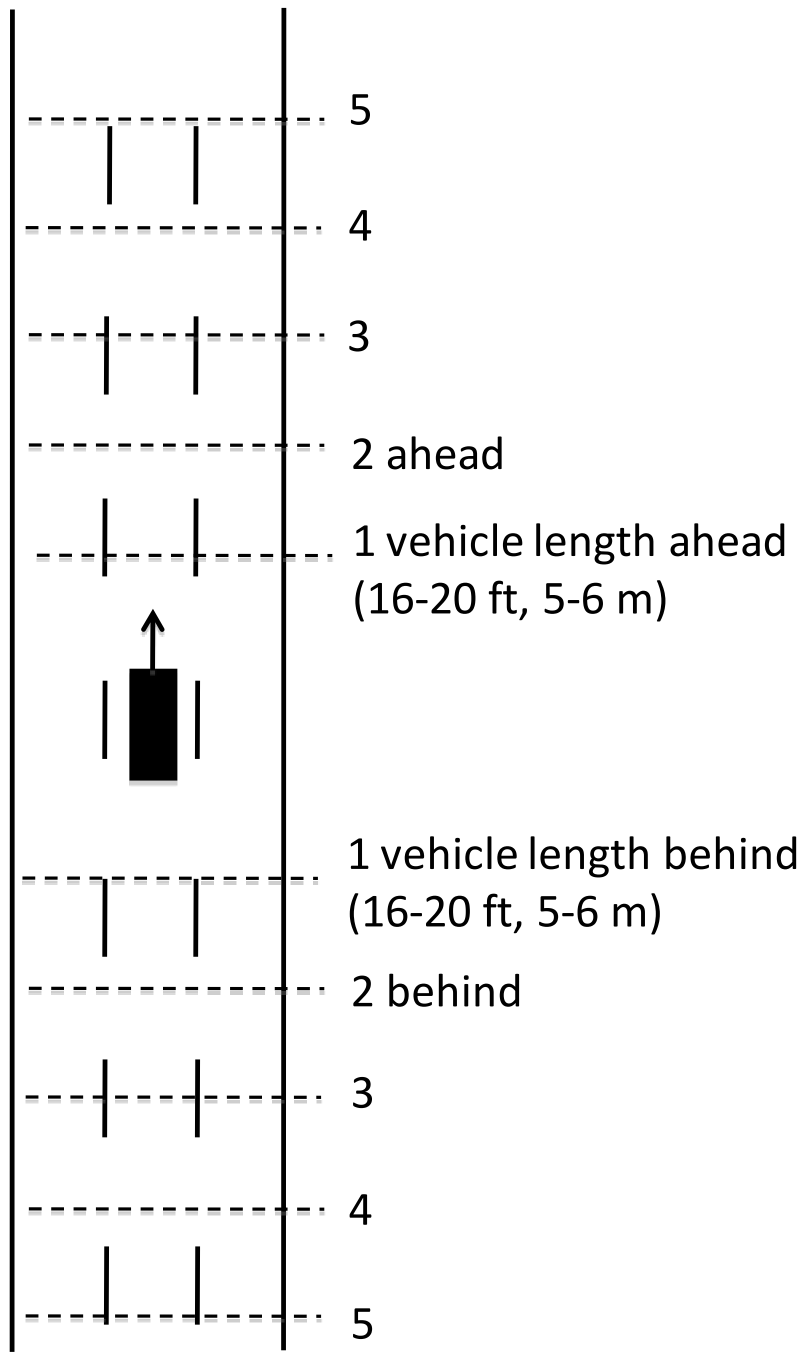


Figure 40. Image Used by Subjects to Record Vehicle Locations

Figure 41. An Example of the Layout of Scenes Shown to Subjects

Appendix L contains the complete set of instructions.

## Participants

Eighteen subjects were recruited via Craigslist (Appendix M) and contacted directly by phone (Appendix N). The 18 subjects were equally split into 6 groups (2 gender x 3 age, 18-30 yr, 35-50 yr, >65 yr). The mean ages of each group of subjects were 22.7, 46.3 and 68.3. The mean mileage of driving was 8,700 miles per year. Two subjects were involved in car crashes during the past 5 years, and 6 subjects had some traffic violations in the past 5 years, all of which were minor crashes or traffic infractions.

# EXPERIMENT 2 - RESULTS

In this experiment, each subject examined 3 sets (3 fields of view - 120°, 150°, or 180°) of 12 pictures (3 mirror configurations x 4 traffic counts) simulating the anchor clips. The traffic count, the number of vehicles in the scene—ahead, to the side, and behind—consisted of 2, 5, 8, or 11 cars. After viewing each set of 12 pictures, subjects recalled where vehicles were shown in the images. Then, they rank ordered the 9 alternatives of same traffic counts (3 mirror configurations x 3 fields of view) from best to worst.

### How Many Cars Were Subjects Aware of?

When the panorama mirror or 3 mirrors was provided, all of the cars were visible. When not provided, subjects could only see 1, 3, 4, and 5 cars instead of 2, 5, 8, and 11 cars, respectively. Although omitting any type of mirror may not make sense, keep in mind that the image size was limited, and adding mirrors could potentially occlude parts of the forward scene.

Subjects' awareness of traffic was evaluated by how well they could recall the locations of the vehicles relative to their car (Figure 42). A recalled vehicle was identified as correct if its location relative to subject was correct. All other situations were treated as errors, including missing (or extra) cars.

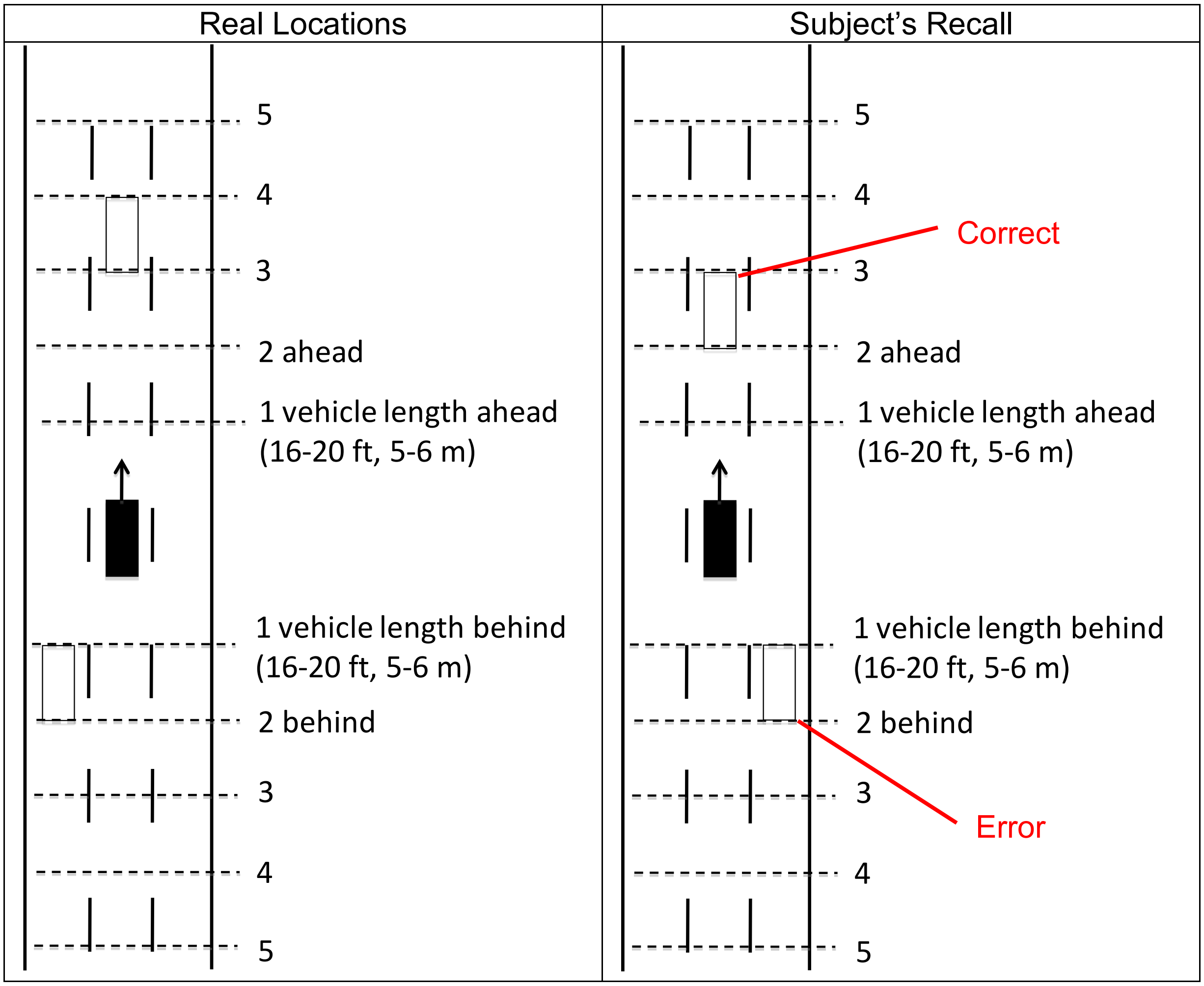


Figure 42. Recall Error Types

Figure 43 shows that for 2 and 5 vehicles in the scene, subjects recalled all that were visible. For the instances of 8 and 11 vehicles, subjects did not recall the presence of all vehicles, with the no mirror interface leading to consistently worse performance. For the no mirror interface, the field of view had no effect on recall. Furthermore, there did not seem to be any differences in recall between the 3 mirror and panoramic interfaces. Strangely, the recall for the 150-degree field of view was slightly worse than that for the 120- and 180-degree field of view conditions.

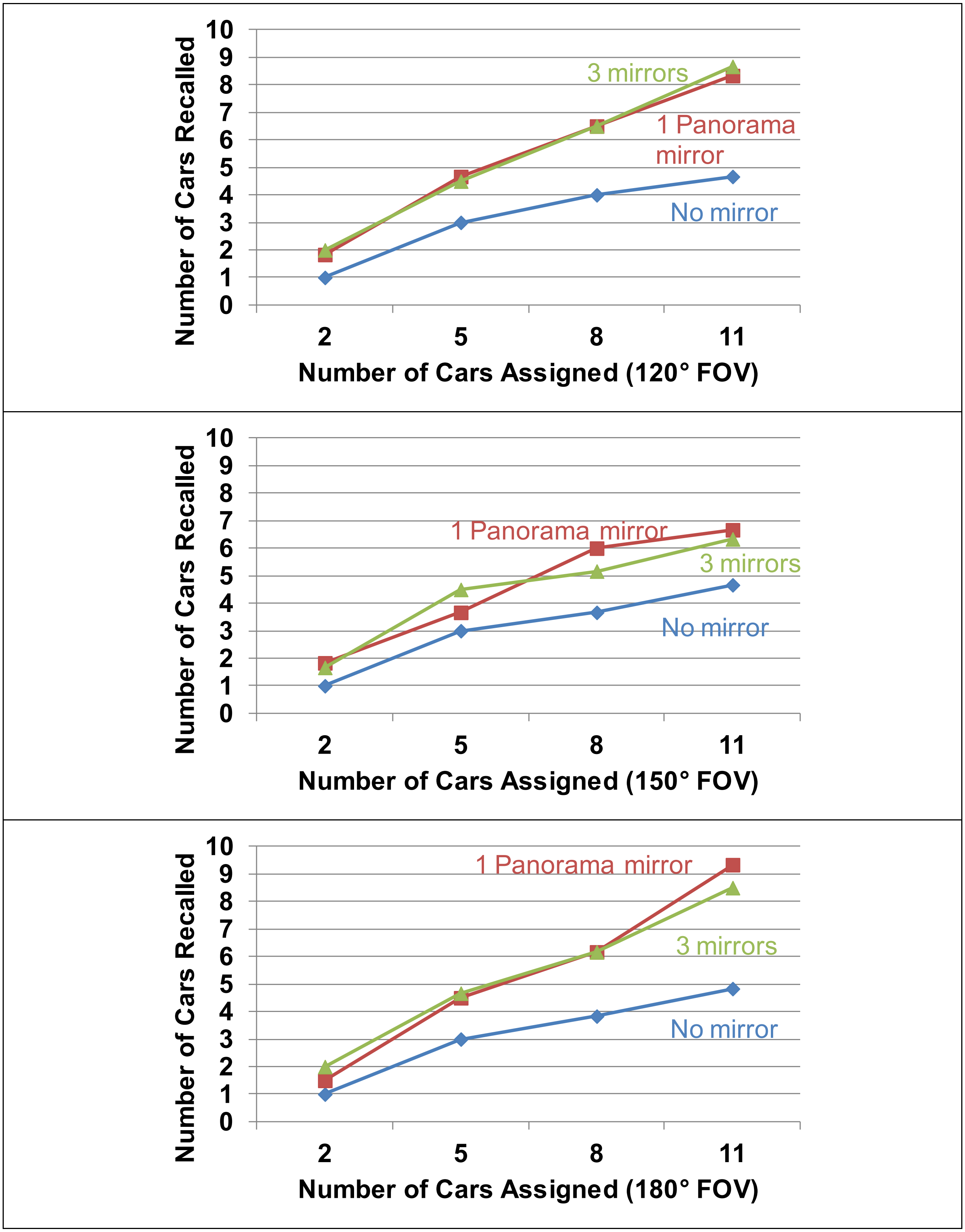


Figure 43. Number of Cars that Subjects Could See and Remember

**How Did the Recall of Cars Vary with Their Locations?**

<u>2 Cars</u>

As a reminder, the number of combinations of vehicle locations with vehicles shown was not a complete factorial due to resource limitation. For the 2-car case, 1 was 3-car lengths ahead and the other was 2-car lengths behind (in the right lane). Subjects always recalled the location of the lead vehicle. However, for the vehicle behind them, recall probability declined as field of view increased as the size of the vehicle in the mirror decreased (as shown in Figure 44) due to scaling issues. Subjects had particular difficulty with the 180-degree field of view-panoramic mirror case, possibly because they were unfamiliar with that type of mirror.

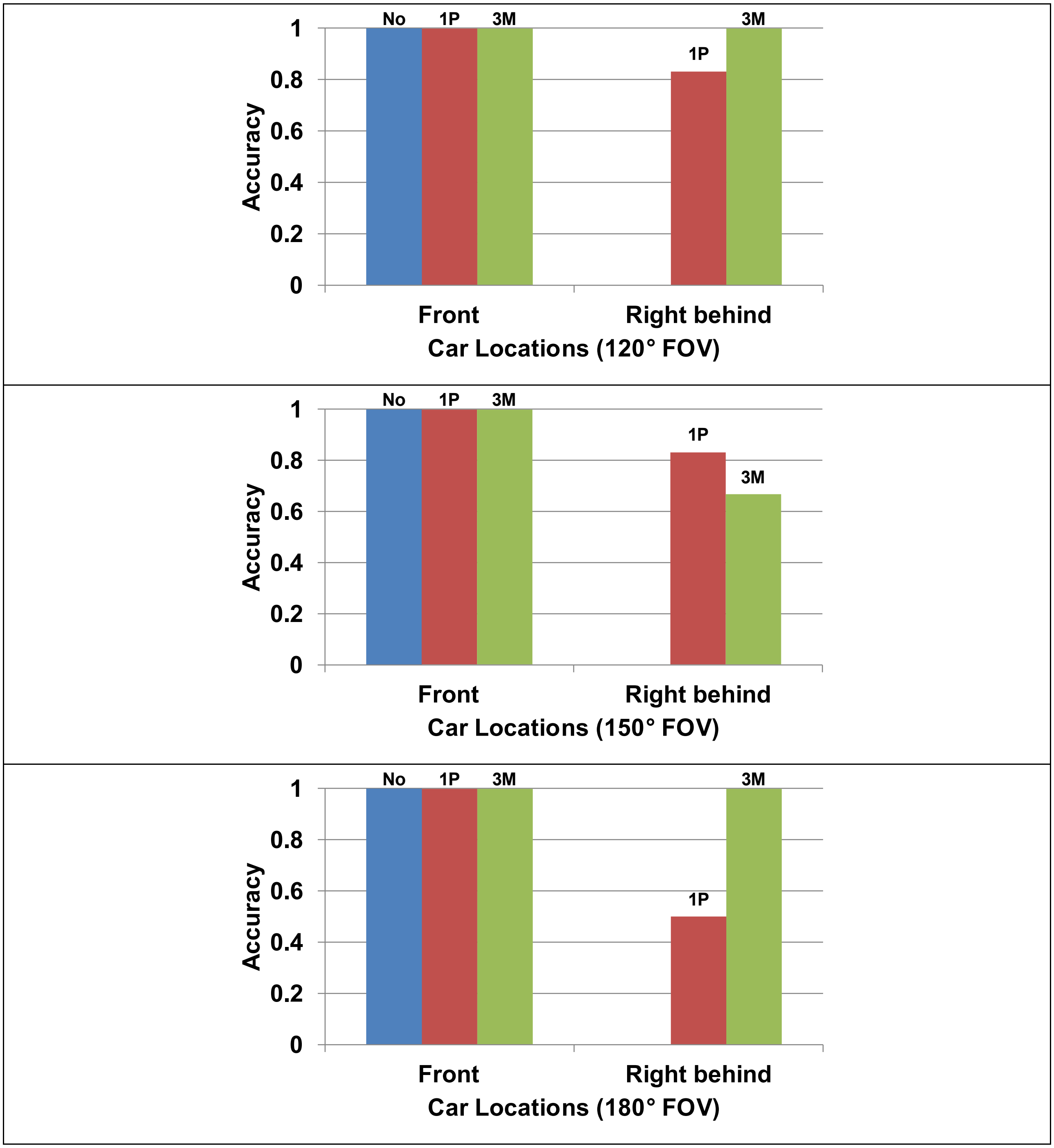


Figure 44. Recall of 2 Cars by Location

5 Cars

When number of cars increased to 5, subjects generally recalled all of the vehicles in front, except for some forgetting in the 150-degree field of view case as was described earlier (Figure 45). They were much less likely to recall the vehicles behind them, in part because these vehicles were shown in mirrors and were smaller.

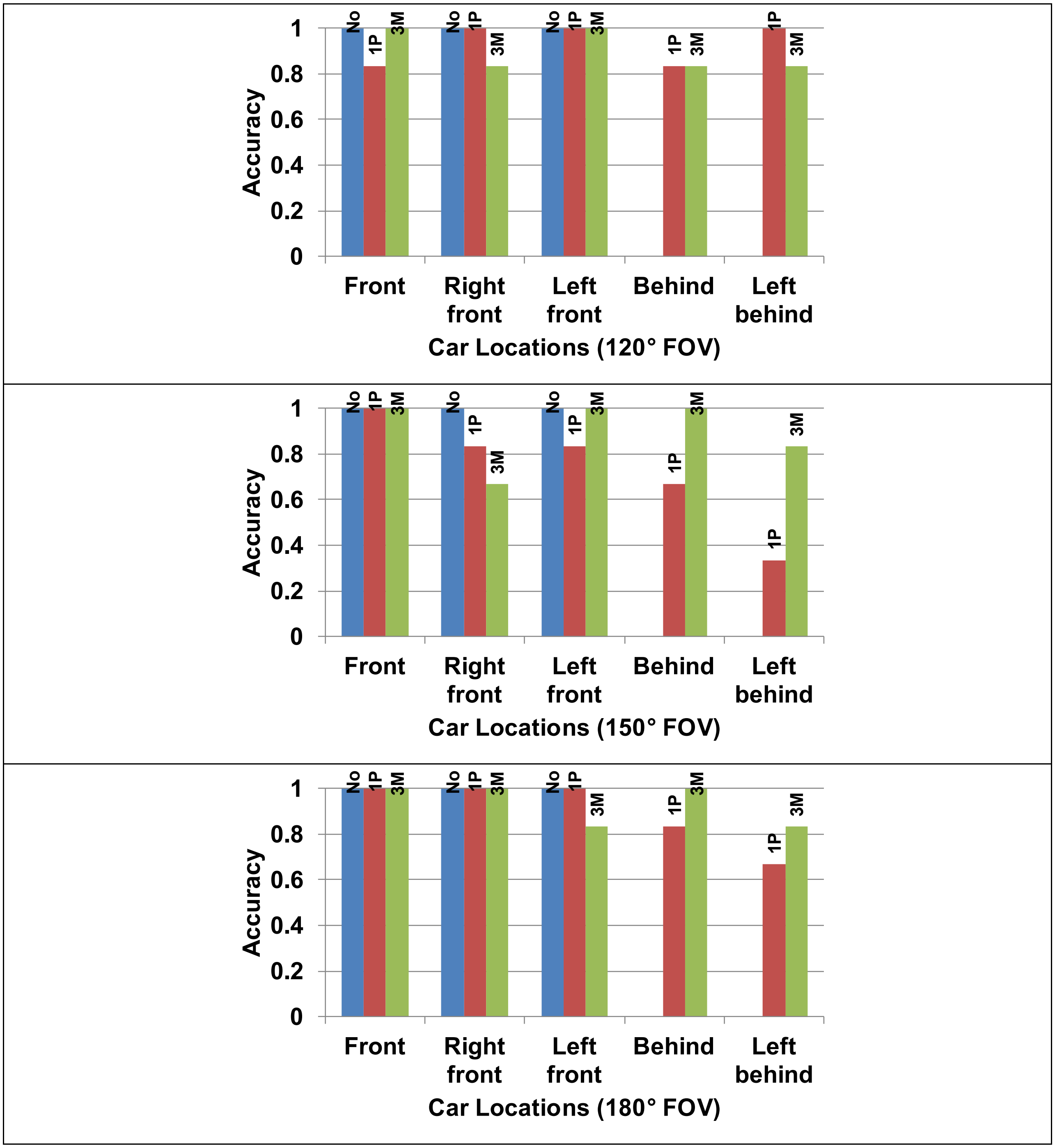


Figure 45. Recall of 5 Cars by Location

<u>8 Cars</u>
In this case, there were 4 cars in front and 4 cars behind the subject. Increasing the field of view did not alter the recall of vehicles to the front, but there was a slight improvement in the recall of side vehicles (Figure 46). The authors have no explanation as to why the recall of cars to the rear varied so widely for panoramic mirrors as a function of the field of view.

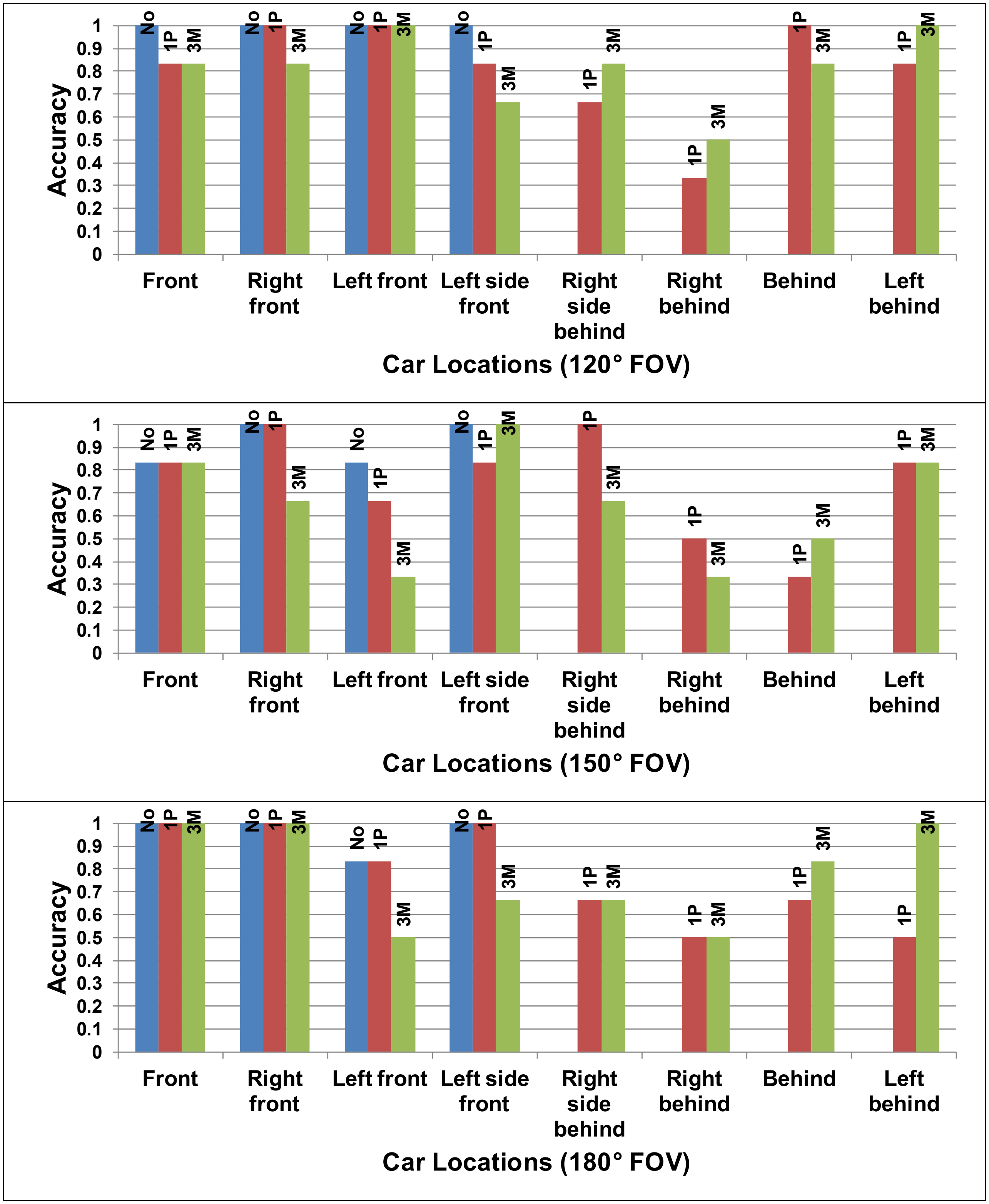


Figure 46. Recall of 8 Cars by Location

11 Cars

For the scenarios with 11 vehicles, the largest number explored, the subject was completely boxed in by traffic (Figure 47). In general, cars to the left were often more likely to be recalled than cars on the right. Not surprisingly, cars that were farther away (and therefore smaller) were less likely to be recalled.

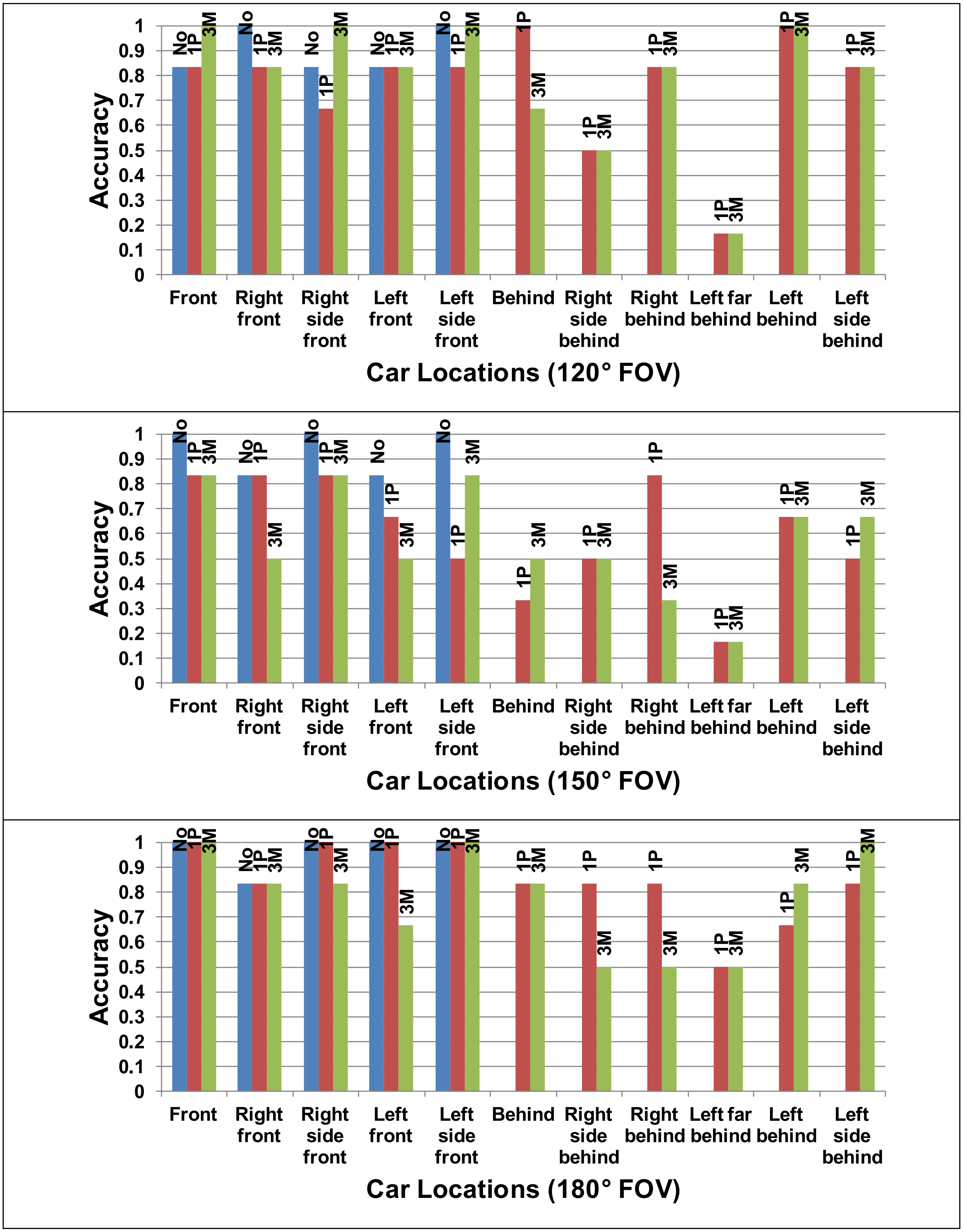


Figure 47. Recall of 11 Cars by Location

In summary, there were several points for anchor clips to guide their design.

1) Subjects recall the locations of up to 5 vehicles without error and begin to forget where cars are located when 8 or more cars are shown.
2) Having mirrors led to better recall than omitting them. But mirrors sometimes blocked the forward scene, so providing them may diminish recall of vehicles in front of the subject vehicle, but that effect proved to be minor. If vehicles were only ahead of subjects, mirrors were obviously not necessary.
3) There was no practical difference in recall between the 3-mirror interface (2 exterior, 1 interior) and the panoramic mirror. Either can be used.
4) Overall there was no practical difference for recall between the 120-degree field of view and 180-degree field of view. However, recall for the 150-degree field of view was worse, a finding for which the authors have no explanation.

Thus, from the performance perspective, for anchor clips, either of the 2 mirror configurations is acceptable for either 120- or 180-degree field of view. If all vehicles are located in front of the subject vehicle, mirrors are not needed.

**What Was the Ranking of Anchor Configurations That Subjects Preferred?**

The 9 combinations of field of view and mirror type were ranked from best to worst separately for each traffic count. Table 12 shows the mean rankings across 18 subjects. Subjects consistently preferred some type of mirror presented to none at all. When few cars were present and subjects were less likely to be boxed in (2: 1 front, 1 behind and 5: 3 front, 2 behind; both without vehicles by the side), subjects preferred 3 mirrors as the large panorama mirror could block the vision to the front if most cars were ahead.

However, for 8 cars or more (8: 4 front, 4 behind & 11: 5 front, 6 behind), the panorama mirror with a wider field of view was preferred. The panorama mirror not only covered more view than regular 3-mirror configuration, but also provided a better integrated view of cars behind the subject. Furthermore, object sizes in the panorama mirror were not as compressed as in the 3-mirror configuration.

Table 12. Subjective Rankings of Interface Configurations

| | 2 cars | | Mean Rank | 5 cars | | Mean Rank |
|---|---|---|---|---|---|---|
| Rank | FOV | Mirror* | | FOV | Mirror | |
| 1 | 180 | 3 | 3.5 | 180 | 3 | 3.2 |
| 2 | 120 | 3 | 3.8 | 120 | 3 | 3.6 |
| 3 | 180 | 1 | 3.9 | 120 | 1 | 3.7 |
| 4 | 150 | 1 | 3.9 | 150 | 1 | 3.8 |
| 5 | 150 | 3 | 3.9 | 150 | 3 | 4.1 |
| 6 | 120 | 1 | 4.1 | 180 | 1 | 4.2 |
| 7 | 150 | N | 7.0 | 180 | N | 7.1 |
| 8 | 180 | N | 7.2 | 150 | N | 7.3 |
| 9 | 120 | N | 7.6 | 120 | N | 8.1 |
| | 8 cars | | Mean Rank | 11 cars | | Mean Rank |
| Rank | FOV | Mirror | | FOV | Mirror | |
| 1 | 180 | 1 | 3.3 | 180 | 1 | 3.4 |
| 2 | 150 | 1 | 3.6 | 150 | 1 | 3.7 |
| 3 | 120 | 3 | 3.6 | 120 | 1 | 3.7 |
| 4 | 150 | 3 | 3.8 | 120 | 3 | 3.9 |
| 5 | 180 | 3 | 4.1 | 150 | 3 | 3.9 |
| 6 | 120 | 1 | 4.3 | 180 | 3 | 4.2 |
| 7 | 180 | N | 7.0 | 180 | N | 7.1 |
| 8 | 150 | N | 7.7 | 150 | N | 7.2 |
| 9 | 120 | N | 7.7 | 120 | N | 7.9 |

* 3=3 mirrors; 1=1 panorama mirror; N=No mirror

**Post-test Questionnaire Analysis**

In the post-test questionnaire, subjects could comment on the interface design including preferences for the field of view of the anchor, for the size of each mirror of 3-mirror configuration, and for locations of mirrors.

From these comments, there was no overall consistent picture for which field of view was desired. Eight subjects ranked their preferences as 180°>150°>120°, 6 subjects indicated 120°>150°>180°, and 4 indicated 150°>180°>120°.

When asked to specify the desired size of mirrors for the scenes, (19 in x 5 in display), the mean size was 1.66 in x 1.08 in for the left exterior mirror (vs. 1.5 x 1 tested), 5.05 in x 0.96 in for the interior mirror (vs. 3.4 x 0.9 tested), and 1.43 in x 0.98 in (vs. 1 x 0.85 tested), for the right exterior mirror. Thus, future studies should present mirrors that are slightly larger than those used in this study. Mirror magnification was not examined.

Although presumably unfamiliar to subjects, in the future, mirrors could be replaced by the rear view monitors and cameras to show rear scenes. Some current vehicles have back-up displays but only to support the interior mirror, not the exterior mirrors. As to the location of these rear-view displays, 12 subjects preferred to the existing 3-mirror locations. There were 2 subjects who each preferred the display put in front of the driver (driver-centered) and on top of the center console. Other opinions included moving the middle mirror only to the center console or top of dashboard, etc.

# CONCLUSIONS

## 1. How and where can the anchor clips be presented in a real vehicle?

Based on pilot tests, to make it easy to compare the road scene with the anchor clips, the display showing the anchor clips needs to be as close as possible to the road scene. If the difference in visual angle of the scenes shown between them is too great, then the comparison is difficult and the ratings will not completely reflect the workload of driving. Furthermore, if the anchor display is too far from the road scene, looking towards that display could be excessively distracting. Thus, a distraction assessment device could induce a distraction problem.

As part of the development of anchors, presenting the anchor clips on a laptop computer or some other in-vehicle display was considered. However, the laptop image was too small. Key details, such as the traffic shown in mirrors that are part of the image, were too difficult to see.

Furthermore, both anchors need to be able to be seen at the same time to facilitate comparison with the forward scene and to minimize time looking away from the road to the anchor clips.

The approach selected was to mount 2 screens, approximately 19 in x 5 in on the hood of the car, with the base of the screens just forward of the base of the windshield. This location blocked seeing just in front of the car slightly, but the risk to driving was minimal. Raising the driver partially compensated for the slight loss of forward downward view.

## 2. How can the anchor clips improve upon those in the previous SAVE-IT and M-CASTL studies?

The most recent versions of the anchor clips were recorded (1) in color, (2) at a higher resolution with resulting improvements in sharpness and anti-aliasing, (3) at 25 Hz (instead of at 1 Hz), and (4) closer to the driver's eye point. To improve rating reliability, the loop time was shortened from 15 s to 5 s and the clips were looped for the entire scenario block.

## 3. How repeatable are the ratings of the video clips?

The mean rating of the first set of driving scenarios was 4.0. The mean rating for those scenarios when driven a second time, but in a different order, was 4.2, hardly different, especially considering ratings were collected to the nearest 0.5. The difference between the 2 ratings achieved statistical significance, but the correlation between means of the 2 sets of ratings (by scenario averaged over subjects) was 0.98. Thus, there was no practical difference between the 2 sets of ratings and they were highly repeatable.

**4. How consistent are the workload ratings scenarios when watching clips with the workload ratings of the same scenarios when driven in the driving simulator?**

Drivers gave higher workload ratings of scenarios they drove in the simulator than for the same scenarios shown in clips (4.3 vs. 3.7). The correlation of mean rating across subjects by scenario of the clips shown to subjects and duplicated in the simulator is 0.84. In the previous M-CASTL results, the correlation was 0.92. Without the 2 special cases (passing traffic and larger-sized vehicle), the ratings for the 2 data sets were 4.5 and 3.6, respectively, a larger difference. However, the correlation was even greater, 0.94. Thus, watching video clips captures some, but not all of the workload of driving, and the 2 sets of ratings are very consistent.

**5. How well is the workload estimated for this experiment with the new anchors and what are the resulting equations?**

With new anchor clips, improved instructions, and more careful control of traffic, the regression equations with 2, 3, and 4 factors were:

Mean workload rating = 8.33 - 3.83*LogGap + 0.49*MeanTrafficCount

Mean workload rating = 8.38 - 3.33*LogGap + 0.33*MeanTrafficCount
+ 4.25*MinimumLanePosition

Mean workload rating = 8.53 - 3.18*LogGap + 0.28*MeanTrafficCount
+ 4.70*MinimumLanePosition - 0.10*StDevSideVehicle2Gap

The variance accounted for by these equations is remarkably high, 80%, 86%, or 89% of the mean rating variance, respectively.

**6. How does the current study compare with the previous studies in terms of (a) the resulting equations and (b) equations with the same factors?**

Across studies, the secondary factors changed. The two primary factors, the logarithm of the gap to the lead vehicle and the number of other vehicles present remain. However, the two secondary factors of the acceleration of subject vehicle and the acceleration of the lead vehicle are replaced by the lane position of subject vehicle and the gap to the side vehicle. The reason was that the position and movement of vehicles in adjacent lanes in this study was systematically varied, so statistics related to them entered the regression equations. The best fitting equation for this experiment accounts for 89 % of the variance, somewhat greater than in previous studies.

Using the same factors of resulting equations from SAVE-IT and M-CASTLE-1 studies, the intercepts and the magnitudes of the coefficients were remarkably similar, especially those from SAVE-IT and this study.

For example, the 2-factor model for the mean workload rating in SAVE-IT was:

Mean workload rating = 8.86 -3.00*LogMeanGap + 0.47* MeanTrafficCount

In the M-CASTL-1 experiment, the equation was:

Mean workload rating = 7.90 – 2.52*LogMeanGap + 0.06* MeanTrafficCount

In this study, the 2-factor model for the mean workload rating was:

Mean workload rating = 8.27 – 3.78*LogMeanGap + 0.50* MeanTrafficCount

The values for the intercepts and slope constants for the 3 and 4-factor models were similarly close.

In the original SAVE-IT experiment, the 2, 3, and 4 factor equations accounted for 82, 87, and 85 % of the variance. In the follow-on M-CASTL-1 study, those same values were 69, 69, and 75% of the variance. In this study, based on stepwise analysis, the values were 80, 86, and 89 % of the variance. However, in this study those data were based on comparing anchor clips with driving in the simulator, whereas the original SAVE-IT anchor clips were compared with other clips, which invariably lead to higher correlations because of the image similarity. Furthermore, one needs to keep in mind that the new scenes were more complex, so lower $R^2$ values would be expected. Thus, the authors' perspective is that the new anchor clips account for at least as much variance as those used previously.

A more direct assessment of the role of the anchors would have had subjects rate the same set of clips twice, once using each set of anchors. However, it was known the clips were flawed and it was deemed to be more useful to allocate subject time to other experimental issues, addressing the old/new anchor comparison between studies using the $R^2$ value. One of those issues was side vehicle position and movement, an important contributor to workload as shown in this experiment.

**7. What else should be shown in the anchor clips?**

Prior to this study, the location of vehicles in adjacent lanes was expected to have an important influence on workload ratings, an expectation supported by the simulator experiment (Experiment 1). To gauge the off-bore sight angle, a frame of reference (the A-pillars, interior mirror, top of the dash from a 2005 Nissan Sentra 1.8S) was added to the images presented in the recall and rating experiment (Experiment 2).

However, for technical reasons, mirrors, whose images needed to be enlarged to 1.7 in x 1.1 in (left exterior, 30 deg FOV), 5.1 in x 1 in (interior, 40 deg FOV), and 1.4 in x 1 in (right exterior, 30 deg FOV) were not included in the anchor clips for the simulator experiment, but should be in future versions. As was shown in the recall and rating experiment, what is happening behind the driver contributes to workload.

A panorama mirror covering 120 deg FOV is a viable alternative to present the rear scene.

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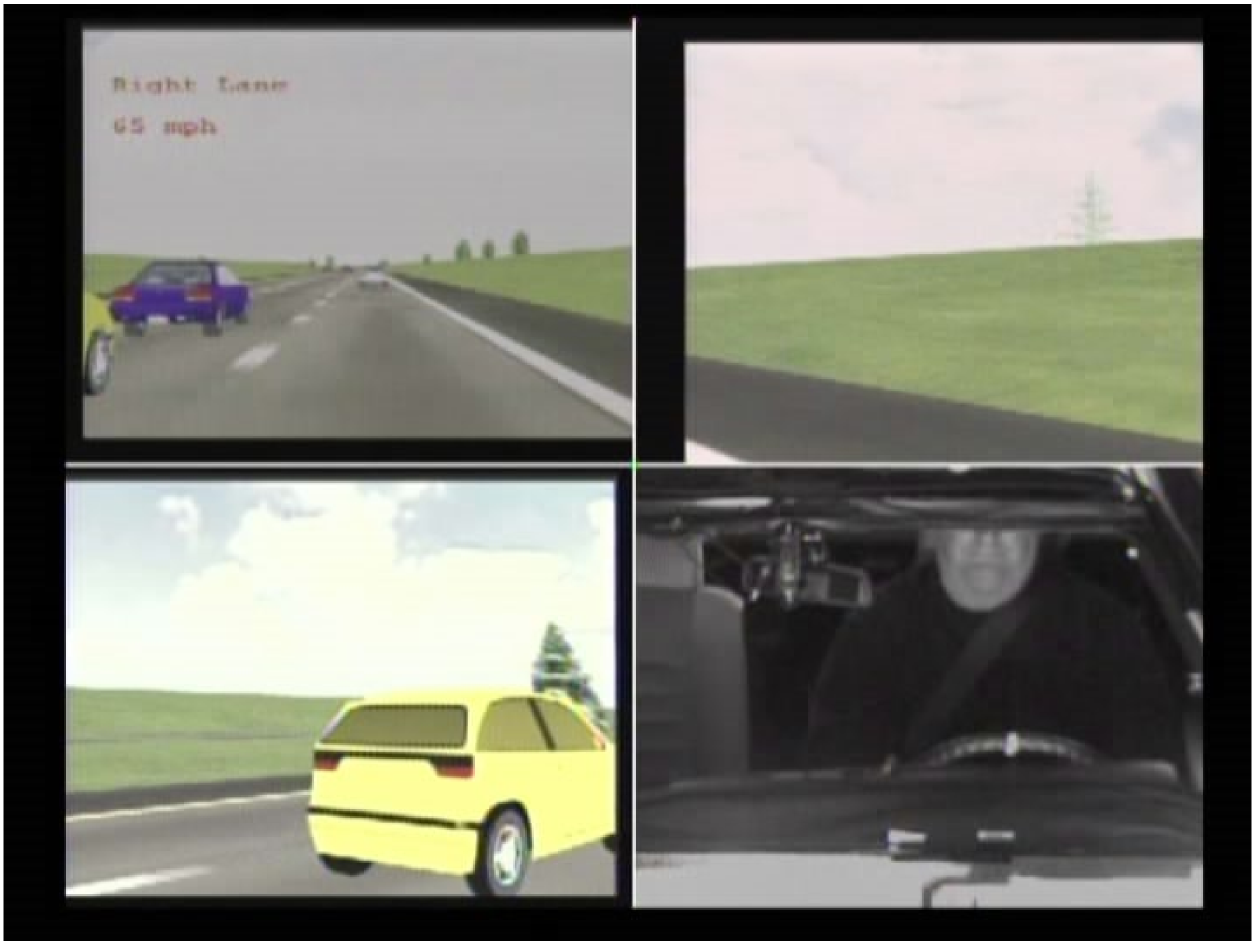
## APPENDIX A - AN EXAMPLE OF THE EXPERIMENT 1 SCENARIO



# APPENDIX B - EXPERIMENT 1 INSTRUCTIONS

### Experiment Setup and Instructions to Subjects: MCASTL Workload Project

**Advance Preparation**
- Turn on simulator and AV system
- Turn on computers for playing anchor clips
- Check audio levels
- Load in DVD (make note to get DVDs if supply is low)
- Make sure there are copies of all forms (consent, bio, post-test, instructions, workload ratings, payment)
- Get cash to pay subjects
- Turn on system to show clips

**Prepare Eye Exam**
- Set up eye examination machine
- Use alcohol swabs to swab eye piece and forehead button

**Prepare Vehicle Simulator**
- Move Seat Back (all the way back)
- Adjust all cameras

**Prepare Computers**
- Open GM Expressway Control
- Open HyperDrive:
  - Open GMExpresswayMCASTL
  - Run
  - Disable "transfer of project…"
- Load Input text file labeled "MCASTL_Practice.txt" for the practice round
- Then load "MCASTL_Block1.txt" or MCASTL_Block2.txt" depending on subject # for the actual round. Have it up on the projectors for mirror alignment.
- Turn ON
  - VHS player
  - Video Component Distributer
  - Audio
  - Multiple outlet Units
  - All four display monitors
  - Monitor above desktop monitors

**<u>Subject Greeting</u>**
- Meet the subject in the lobby
- Introduce yourself and verify the subject:

"**Hello, my name is** - **<u>State your name,</u> You must be - <u>State Subject Name</u>"**
**"Since this experiment involves driving, we need to verify you are a licensed driver. May I please see your driver's license?"** Check driver's license for vision restrictions, correct date of birth, and expiration date.

Return driver's license

- Ask if the subject wants to go to the restroom or get a drink
- Go to the conference room on the 3rd floor
- Verify the subject's and experimenter's cellular phone / pagers are OFF

**Subject Forms**

- Fill out Consent Form.
  **"As was noted when you were contacted earlier, we are carrying out a study of the workload of driving. While driving, people are doing all sorts of things in addition to controlling the vehicle—using phones, entering navigation information, and so forth. To determine how much is too much for drivers to do, the first step is to quantify the workload of just driving without those additional tasks. In this experiment, you will rate the workload of a variety of situations in the driving simulator.**
  **As a precaution, there are times when some people in this experiment experience motion discomfort. If at any time you have a problem, let us know. We will pay you in full even if you do not complete the experiment.**
  **To document what we do, we videotape subjects and show outtakes of those tapes to the sponsor and the public. We want to make sure using outtakes from you is acceptable, because if it is not, you cannot participate."**
  **Ok, given that, please read the consent form carefully, as it provides some additional details about the experiment. If you are willing to participate, then sign the consent form."**
  Give them the bio form, make sure they read it and sign it.

- Fill out bio form
- **"We need a few facts about you, so please fill out this biographical form."**

**Vision test**

- **"Since how well you drive depends on how well you see, we need to check your vision. Put your glasses on or contacts in if you have not already done so. Please place your forehead against the button. For the entire test, keep looking straight ahead."**
  For each number or letter they get right, circle the number. For each number they get wrong, slash the number or letter. End the test when the subject gets two consecutively incorrect.
  "**Thank you very much."** or **"That's all I need, thank you."**

- Test visual acuity (FAR #2)
  **"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right."**

- Test near vision (80 cm) (FAR #2) with Lenses

**"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right."**

<u>**In-Simulator: Parked**</u>

Walk down or elevate down to the simulator. Flip the sign on the door. Chain the door shut.

- Have the subject seated in the cab.

Introduce the screens to play anchors

**"In the driving simulator session today, you will drive a wide range of scenarios and rate the workload of each. Your ratings of workload will be relative to these 2 reference clips."**

Play the anchors.

**"So, if the workload of a driving scenario was equivalent to the example on the left, the lower workload level, it would be rated as 2. If the workload was equal to the scenario on the right, then it would be a 6. The greater the workload is, the larger the number will be. However, most of the situations will not be equal to those values, but maybe in between, or greater or smaller. So, ratings could be 1 or 3 or 8, or even 4.5. In fact, most people find they cannot rate the workload any more accurately than the nearest ½ point. Even if you might prefer to use values other than 2 or 6 for the reference clips, please use those values.**

- Practice Driving and Rating

**"Now we can start the driving experiment. As was noted when we first contacted you and on the consent form, there is a chance that subjects can experience motion discomfort. To make sure that is not a problem, there will be some short practice drives. Follow the road and drive with traffic at the posted speed limit. For some trials, changing lanes is required. Please use your turning signals and check the traffic. Unfortunately, the turn signal sound is not working at the moment."**

**"In this experiment, the driving conditions are continually changing. To reduce variability in the rating process, the ratings will be the average workload over 15 second intervals, not just when you give the rating. You will hear a recorded female voice announce when the rating people begins. She will say, "Please consider the driving workload over the next 15 seconds." When you hear "Please give the 15 second workload rating now," say the average workload rating was for the entire 15 seconds. Do you have any questions?**

**"To help you understand this process, there will be a few practice trials. Are you ready?"**

Start the rating practice block.

**"Ok, you have the idea. Bring the vehicle to a stop, put the car in park, and I will load the first of 2 experimental roads."**

Make sure they do not correct excessively. If they do, intervene. If there are indications of motion sickness, say, **"Please bring the vehicle slowly to a stop."**

After they have done so, say:
**"It appears you are among those who is susceptible to motion and participating further is not recommended. However, we will pay you in full for coming today."**
Pay them and have them sign the payment form.

**<u>Main Experiment Driving and Rating</u>**

**"The first road is going to be loaded. Periodically, I will remind you to change lanes and speed in addition to rating the workload.**
**There are a couple of reminders.**

1. **Even if you appear to be closing in on a car, please keep your speed constant. We are collecting driver's workload, not your response.**
2. **Before giving the rating, remember to compare the driving scenario to the reference clips, assigned values of 2 and 6.**
3. 

Load in the first test road.
**"Are you ready? Put the car into drive and follow the instructions. The road takes about 20 minutes to drive."**

Make sure you check their speed and lane, and get the ratings needed (start, end).

**"You are near the end of the road, so pull off to the side of the road, gently bring the car to a stop, and put it in park."**
Afterwards, "**Give me a moment to save the data and load in 1 more road."**
Note: Block two is in the same txt. file as block 1. All you need to do is save the data and move to block 2 in the GM expressway control screen.

Save the data and load in the second test road.

**"Ready? The process is again the same. Drive the request speed, changing lanes as needed, and rate the workload when requested."**
Note: Some means is need to get subjects to change lanes at the desired locations and to change speeds as well. Signs might be helpful.
Collect the ratings while driving.

**“Bring the vehicle to a stop, put the car in park, and I will save the data.”**
Save the data.

**<u>Post Test</u>**

Posttest workload evaluation

**“In this segment, we would like to you rate the workload to several video clips of driving scenarios relative to the 2 reference clips. The clips will appear on the big center screen. For these scenes, you need to pretend you were driving in them.**

**Ok, rate the workload of this clip relative to the reference clips, 2 and 6.**
They rate the clips.

Play video clips by the orders in the posttest form.

**“Do you have any comments?”**

**“We have 3 final questions, and then you are done. “First, when you looked at scenes in the simulator, what things did you consider that led you to give a high or low workload rating?**

Follow up on what they say, to get them to be more specific. <u>Absolutely avoid leading questions.</u>

Examples
When considering ** (for example distance, number of vehicles, etc.-let them say it), when there was more/greater, did workload increase?

If the subject said the cars in the scene influenced their rating, then follow up with “what about the cars did you consider?”
If they said they considered the road, then ask what about the road they considered.

**Some have suggested the items on these cards influenced workload ratings in <u>this</u> experiment. (**Note: Each item should be on a separate card. **To make sure I do not bias your response, I am shuffling them so the order is random. Rank order them from most to least important.** Put the numbers 1-9 on the back of the cards to aid recording. Have a sheet on the table with a scale and the words “most important” and “least important.”

1. Distance to the lead vehicle (directly ahead in your lane)
2. If the lead vehicle is accelerating or decelerating
3. Number of cars in the scene
4. Color of cars in the scene

5. Distance to the closest vehicle in the next lane
6. If the closest car in the next lane is accelerating or decelerating
7. Lane in which you are driving
8. Speed you were driving on the expressway
9. Other factors (say what they are)

Record their ratings. Double check that all 8 or 9 items are considered. Make sure that all 8 or 9 items are ranked and there are no duplicates (the same item is recorded twice and some are missing).

Finally, when you rated the workload of the driving scenarios while you were driving and while watching the clips, which of these items did you consider?

Yes no Distance to the lead vehicle (directly ahead in your lane)

Yes no If the lead vehicle is accelerating or decelerating

Yes no Number of cars in the scene

Yes no Color of cars in the scene

Yes no Distance to the closest vehicle in the next lane

Yes no If the closest car in the next lane is accelerating or decelerating

Yes no Lane in which you are driving

Yes no Speed you were driving on the expressway

Yes no Other factors (say way they are)

**Thank you for helping us. Here is $40. Please sign this payment form so we can get reimbursed."**
Pay the subjects. The subject signs the form.

**<u>Subject Wrap up</u>**
- Walk subject to the front door
- Flip sign on door

# APPENDIX C - EXPERIMENT 1 CONSENT FORM

| UMTRI<br>University of Michigan<br>Transportation Research Institute<br>2901 Baxter Road, Ann Arbor, MI 48109-2150 | Participant # _________ |
|---|---|

# Consent Form

**Development of a Protocol to Assess the Workload of Driving**

**Investigator: Paul Green (763 3795) UMTRI Driver Interface Group**

To determine how much is too much for drivers to do while driving (and when it might be unsafe), we need to measure the workload (the demand) of driving the vehicle and the added workload of other activities such as using a phone or a navigation system. In this first step, we will quantify the workload of the just driving the vehicle.

After providing biographical data (your age, driving experience, etc.) and driving data (e.g., miles drive/year), you will practice driving the simulator while rating the workload of driving on a scale we created. You cannot actually crash in the simulation because the car is invincible. Next, while being videotaped, you will drive on a simulated 3-lane expressway with varying amounts of traffic following the directions of the experimenter, again rating the workload relative to some video clips. Finally, at the end, there will be a brief questionnaire.

This is an evaluation of the workload of driving, not your skill or ability to drive. Participation in this research is voluntary and you may skip any question you wish or quit at any time without consequence.

There is a possibility of motion discomfort while driving the simulator. If that occurs, please let the experimenter know immediately and we will stop the experiment. You may withdraw from this study at any time without penalty. You will be paid $40 for your time. Of course, there are no costs to you since UMTRI parking is free. The study should take about 1.5-2 hours.

Summaries of what you did (but not your name) will appear in a publicly available report whose results will make future vehicles that you may drive less distracting and safer. Records will be kept confidential to the extent provided by federal, state, and local law, though various officials can inspect them.

At any time, should you have questions regarding your rights as a participant in research, please contact the Institutional Review Board, Behavioral Sciences, 540 E. Liberty # 202, Ann Arbor, MI 48104, (734) 936-0933, email: irbhsbs@umich.edu.

**As was stated when you were scheduled for this experiment, all participants must be "videotaped". I therefore agree to be recorded and realize my face will appear on the recording. I understand that segments from the recordings of my sessions may be used in presentations by the authors, by the sponsor, and by the media (e.g., on TV) to help explain this research. My full name will not be disclosed with the recording. The raw recordings will be discarded 10 years after the project is completed.**

I have read and understand the information presented above, and all of my questions have been answered. My participation is voluntary. I agree to participate.

| | |
|---|---|
| ______________________ | ______________________ |
| Print your name | Date |
| ______________________ | ______________________ |
| Sign your name | Witness (experimenter) |

Note: Keep one copy for the records and give the other to the participant.

# APPENDIX D - EXPERIMENT 1 BIOGRAPHICAL FORM

**Workload of Driving – Biographical Form** **Participant # _____**

**You**
Name ________________________________________________
Phone: ________________________
Email address __________________________________________
May we email you for future studies? yes no
Born (month / day / yr) ___ / ___ / ___
Occupation: _______________ (if retired: main occupation before retirement)
Education (circle highest level completed and fill in blank)
High-School Some-College College-Degree Graduate-School
Major ______________ (Ex: Cognitive Psychology, Micro-Biology, Accounting)

**Your Driving**
What motor vehicle do you drive most often?
Year: _______________ Make: ______________ Model: ______________
How many miles do you drive per year? ___________
What lane of a 3-lane highway do you normally drive in? Left Middle Right
Do you have any special driving licenses (e.g. heavy truck) and if so, what kind?
No Yes: explain -> ________________
In how many accidents have you been involved during the past 5 years? ________
In how many traffic violations have you been involved in the past 5 years? _______
Details: ________________________________________________________

**Your Vision** Circle what vision correction you use
When driving: no-correction contacts glasses: multifocal, bifocal, reading, far-vision
When reading: no-correction contacts glasses: multifocal, bifocal, reading, far-vision

***For the experimenter only*** *12526616*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Far Acuity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | T | R | R | L | T | B | L | R | L | B | R | B | T | R |
| | 20/200 | 100 | 70 | 50 | 40 | 35 | 30 | 25 | 22 | 20 | 18 | 17 | 15 | 13 |
| 80 cm Acuity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | T | R | R | L | T | B | L | R | L | B | R | B | T | R |
| Color-Abnormality | A | B | C | D | E | F | | | | | | | | |
| | 12 | 5 | 26 | 6 | 16 | ~ | | | | | | | | |

# APPENDIX E - EXPERIMENT 1 POST TEST FORM

### Estimation of Driving Workload from Video Clips

To relate what you just did to a prior experiment, in this portion of the experiment, there is no driving. We will show you several test clips, and you will rate them relative to the same anchor clips (2 and 6) as before.

| | Clip # | Workload Rating | | Clip # | Workload Rating |
|---|---|---|---|---|---|
| 1 | 19-1 | | 7 | 13 | |
| 2 | 25 | | 8 | 4.5 | |
| 3 | 11 | | 9 | 1 | |
| 4 | 31 | | 10 | 17-1 | |
| 5 | 21-2 | | 11 | 22 | |
| 6 | 2 | | 12 | 5 | |

Please answer the following questions:

1. When you looked at scenes in the simulator, what things did you consider that led you to give a high or low workload rating? (Follow up on what they say, to get them to be more specific. When considering ** (for example distance, number of vehicles, etc.-let them say it), when there was more/greater, did workload increase?

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

2. Some have suggested the following items influenced workload ratings in <u>this</u> experiment. Rank order them from most to least important. (Note: Each item should be on a separate card. Make sure the subject sees you shuffle the cards before you

lay them on a table so they know the order is random. Put the numbers 1-9 on the back of the cards to aid recording

1. Distance to the lead vehicle (directly ahead in your lane)
2. If the lead vehicle is accelerating or decelerating
3. Number of cars in the scene
4. Color of cars in the scene
5. Distance to the closest vehicle in the next lane
6. If the closest car in the next lane is accelerating or decelerating
7. Lane in which you are driving
8. Speed you were driving on the expressway
9. Other factors (say what they are)

most to least ____ ____ ____ ____ ____ ____ ____ ____ ____

3. When you rated the workload of the driving scenarios while you were driving and while watching the clips, which of these items did you consider?

Yes no Distance to the lead vehicle (directly ahead in your lane)
Yes no If the lead vehicle is accelerating or decelerating
Yes no Number of cars in the scene
Yes no Color of cars in the scene
Yes no Distance to the closest vehicle in the next lane
Yes no If the closest car in the next lane is accelerating or decelerating
Yes no Lane in which you are driving
Yes no Speed you were driving on the expressway
Yes no Other factors (say way they are)

______________________________

# APPENDIX F - EXPERIMENT 1 CRAIGSLIST POST

Subjects Needed for Driving in a Simulator
University of Michigan Transportation Research Institute (UMTRI)

We are conducting an experiment to help reduce accidents related to distracted driving.
We are collecting the workload, or the demand of driving of various road conditions.
The experiment is conducted at UMTRI in a driving simulator.
We are looking for licensed drivers, ages 18-30, and over 65. The experiment lasts 1.5 to 2 hours and pays $40.
Call Brian, Monday through Friday, 9am – 7pm.

# APPENDIX G - EXPERIMENT 1 PHONE SPIEL

**"We are conducting an experiment to help reduce problems related to distracted driving—use of cell phones, complex navigation systems, and so forth. To determine how much is too much for drivers to do, we first need to know what is the demand, the workload, of just driving a vehicle.**

**To determine that, we will have people, maybe you, drive our simulator in various traffic situations and rate the workload of driving using a method we developed. The experiment is quite straightforward, and the only concern is that some drivers can get motion sickness. However, either you or we will stop the experiment before that occurs.**

**Also, you should know that we will videotape the experiment and will show outtakes to the sponsor and the public.**

**The experiment pays $40 for 1.5-2 hours and takes place at UMTRI. Are you interested?"**

If yes, record their name, phone number, and email address and schedule a time for the experiment.

**"If you wear glasses when you drive, please bring them."**

**"If there is a problem with this date or time, please call me** (give your name and phone number) **or email me at** (your email address). They will then scramble for a pen and paper, and ask you to repeat the information. If you just ask them to write it down, they will not.

# APPENDIX H - EXPERIMENT 2 CONSENT FORM

| UMTRI UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE | Participant # ________ |
|---|---|

## Consent Form

**Development of a Protocol to Assess the Workload of Driving**

**Investigator: Paul Green (763 3795) UMTRI Driver Interface Group**

To determine how much is too much for drivers to do while driving (and when it might be unsafe), we need to measure the workload (the demand) of driving the vehicle and the added workload of other activities such as using a phone or a navigation system. To conduct studies examining these topics, we need to show the entire driving situation--front, rear, and sides--on a single display.

After providing biographical data (your age, driving experience, etc.), driving data (e.g., miles drive/year), and checking your vision, you will be shown several examples of driving scenes in the conference room depicted in various ways. While being videotaped, you need to rank order these ways from best to worst in terms of conveying workload. You will repeat the ranking process for several times for different scenes. Finally, at the end, there will be a brief questionnaire.

Participation in this research is voluntary and you may skip any question you wish or quit at any time without consequences.

There is no apparent risk in this survey, but you may still withdraw from this study at any time without penalty. You will be paid $25 for your time. Of course, there are no costs to you since UMTRI parking is free. The study should take about 1 hour.

Summaries of what you did (but not your name) and how you ranked will appear in a publicly available report whose results will make future vehicles that you may drive less distracting and safer. Records will be kept confidential to the extent provided by federal, state, and local law, though various officials can inspect them.

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board, 540 E Liberty St., Ste 202, Ann Arbor, MI 48104-2210, (734) 936-0933 [or toll free, (866) 936-0933], irbhsbs@umich.edu."

> **As was stated when you were scheduled for this experiment, all participants must be "videotaped". I therefore agree to be recorded and realize my face will appear on the recording. I understand that segments from the recordings of my sessions may be used in presentations by the authors, by the sponsor, and by the media (e.g., on TV) to help explain this research. My full name will not be disclosed with the recording. The raw recordings will be discarded 10 years after the project is completed.**

I have read and understand the information presented above, and all of my questions have been answered. My participation is voluntary. I agree to participate.

| | |
|---|---|
| ____________________ Print your name | ____________________ Date |
| ____________________ Sign your name | ____________________ Witness (experimenter) |

Note: Keep one copy for the records and give the other to the participant.

# APPENDIX I - EXPERIMENT 2 BIOGRAPHICAL FORM

UMTRI
UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

**Workload of Driving – Biographical Form** **Participant # _____**

**You**
Name ____________________________________________
Phone: ______________________
Email address ______________________________________
May we email you for future studies? yes no
Born (month / day / yr) ___ / ___ / ___
Occupation: ______________ (if retired: main occupation before retirement)
Education (circle highest level completed and fill in blank)
High-School Some-College College-Degree Graduate-School
Major _____________ (Ex: Cognitive Psychology, Microbiology, Accounting)

**Your Driving**
What motor vehicle do you drive most often?
Year: ______________ Make: _____________ Model: _____________
How many miles do you drive per year? __________
What lane of a 3-lane highway do you normally drive in? Left Middle Right
Do you have any special driving licenses (e.g. heavy truck) and if so, what kind?
No Yes: explain -> ______________
In how many accidents have you been involved during the past 5 years? _______
In how many traffic violations have you been involved in the past 5 years? _______
Details: ______________________________________________

***For the experimenter only*** *12526616*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Far Acuity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | T | R | R | L | T | B | L | R | L | B | R | B | T | R |
| | 20/200 | 100 | 70 | 50 | 40 | 35 | 30 | 25 | 22 | 20 | 18 | 17 | 15 | 13 |
| 80 cm Acuity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | T | R | R | L | T | B | L | R | L | B | R | B | T | R |
| Color-Abnormality | A | B | C | D | E | F | | | | | | | | |
| | 12 | 5 | 26 | 6 | 16 | ~ | | | | | | | | |

## APPENDIX J - EXPERIMENT 2 POST TEST FORM

1. Front Field of View (FOV)

When driving you need to see where you are going and what could run into you.  For a fixed display size, a wider the field of view lets you see more, but the objects are smaller.  In this experiment, fields of 120, 150, and 180 degree were shown (See below or the printout plan view pictures).  Given this tradeoff, rank these 3 options from best (1) to worst (3).

120 degree

150 degree

180 degree

Ranking:

120________; 150________; 180________

2. Rear Display Size

Drivers also need to be aware of what is behind them, which they can see in mirrors and monitors (connected to rear cameras).  Given that, there are tradeoffs, as the larger the rear images, the more the front and side images are blocked.

If you can change these rear images to be more useful to you, how would you do it, given the overall display size, the size of the entire image, is fixed?  Would you make any of them bigger or smaller?  Use the following examples as the reference to give the size of the display.  Here is a ruler to help you establish the size.

| Mirror | Current size (inch) | Your preference (inch) |
|---|---|---|
| | Width x height | Width x height |
| Left | 1.5 x 1 | |
| Middle | 3.4 x 0.9 | |
| Right | 1 x 0.85 | |

Using 180 degree FOV as an example

Display of regular view:

Display of panorama view:
Middle:  10 inch by 0.9 inch (~3 times wider than regular one)

3. Rear Display Location

Would you change their locations? Please choose from the options (you can also make adjustment from the listed options).

Location (s):

_____ (a) As is. No change.

_____ (b) Driver-centered

_____ (c) Center console

_____ (d) Others. Please mark them in the picture.

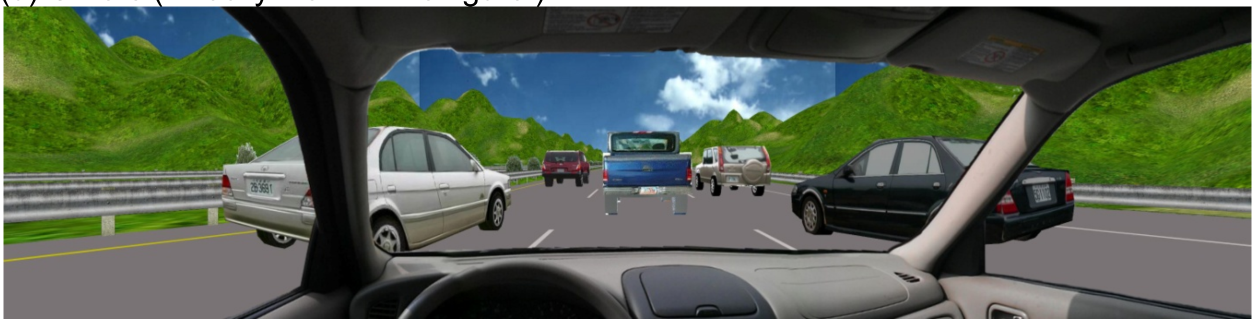
Using 180 degree FOV as an example

(a) As-is

(b) Driver-centered

(c) Center console

(d) Others (Directly mark in the figure.)



4. Besides the factors in the experiment, rear display location, front field of view, and traffic surrounded, what else you think that could affect your awareness of driving situations?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

# APPENDIX K - EXPERIMENT 2 TEST SEQUENCE

Training: No – 1 Panorama – 3 Mirrors.  The FOV is based on subject's group.

| Orders | FOV | Mirror allocation | A: 2 cars<br>B: 5 cars<br>C: 8 cars<br>D: 11 cars | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|---|---|---|
| 1 | 120 | No | C | v | | |
| 2 | 120 | 3 Mirrors | A | v | | |
| 3 | 120 | 1 Panorama | D | v | | |
| 4 | 120 | No | D | v | | |
| 5 | 120 | 1 Panorama | A | v | | |
| 6 | 120 | 3 Mirrors | B | v | | |
| 7 | 120 | 1 Panorama | C | v | | |
| 8 | 120 | No | A | v | | |
| 9 | 120 | 3 Mirrors | C | v | | |
| 10 | 120 | No | B | v | | |
| 11 | 120 | 1 Panorama | B | v | | |
| 12 | 120 | 3 Mirrors | D | v | | |
| 1 | 150 | 1 Panorama | A | | v | |
| 2 | 150 | No | A | | v | |
| 3 | 150 | 1 Panorama | B | | v | |
| 4 | 150 | 3 Mirrors | D | | v | |
| 5 | 150 | 1 Panorama | D | | v | |
| 6 | 150 | No | C | | v | |
| 7 | 150 | 3 Mirrors | C | | v | |
| 8 | 150 | 3 Mirrors | A | | v | |
| 9 | 150 | 1 Panorama | C | | v | |
| 10 | 150 | 3 Mirrors | B | | v | |
| 11 | 150 | No | B | | v | |
| 12 | 150 | No | D | | v | |
| 1 | 180 | 3 Mirrors | B | | | v |
| 2 | 180 | 3 Mirrors | C | | | v |
| 3 | 180 | 1 Panorama | D | | | v |
| 4 | 180 | No | B | | | v |
| 5 | 180 | 1 Panorama | C | | | v |
| 6 | 180 | 3 Mirrors | D | | | v |
| 7 | 180 | No | C | | | v |
| 8 | 180 | 1 Panorama | A | | | v |
| 9 | 180 | 3 Mirrors | A | | | v |
| 10 | 180 | No | D | | | v |
| 11 | 180 | No | A | | | v |
| 12 | 180 | 1 Panorama | B | | | v |

# APPENDIX L - EXPERIMENT 2 EXPERIMENT INSTRUCTIONS

### Experiment Setup and Instructions to Subjects: MCASTL Workload Project II

**Advance Preparation**

- Make sure there are copies of all forms (consent, bio, post-test, instructions, workload ratings, payment)
- Get cash ($25) to pay subjects

**Prepare Eye Exam**

- Set up eye examination machine
- Use alcohol swabs to swab eye piece and forehead button

**<u>Subject Greeting</u>**

- Meet the subject in the lobby
- Introduce yourself and verify the subject:

"**Hello, my name is** - **<u>state your name</u>, You must be - <u>state subject name</u>"**
**"Since this experiment involves displays that present driving situations, we need to verify you are a licensed driver. May I please see your driver's license?"**
Check driver's license for vision restrictions, correct date of birth, and expiration date.
Return driver's license

- Ask if the subject wants to go to the restroom or get a drink
- Go to the conference room on the 3rd floor
- Verify the subject's and experimenter's cellular phone / pagers are OFF

**<u>Subject Forms</u>**

- Fill out Consent Form.
  **"As was noted when you were contacted earlier, we are carrying out a study of a new display. Its purpose is to show the entire driving situation on a single display, emphasizing what the driver needs to see most. Your task is to rank order the ideas for displays from best to worst.**

  **If at any time you have a problem, let us know. We will pay you in full even if you do not complete the experiment.**

  **To document what we do and your comments, we will videotape you and show outtakes of those tapes to the sponsor and the public. We want to make sure using outtakes from you is acceptable. If it is not, you cannot participate."**

  **Ok, given that, please read the consent form carefully, as it provides some additional details about this experiment. If you are willing to participate, then sign the consent form."**
  Give them the bio form, make sure they read it and sign it.

- Fill out bio form

- **"We need a few facts about you, so please fill out this biographical form."**

__**Vision test**__

- **"Since how well you see a display depends on how well you see, we need to check your vision. Put your glasses on or contacts in if you have not already done so. Please place your forehead against the button. For the entire test, keep looking straight ahead."**
  For each number or letter they get right, circle the number. For each number they get wrong, slash the number or letter. End the test when the subject gets two consecutively incorrect.
  "**Thank you very much."** or **"That's all I need, thank you."**

- Test visual acuity (FAR #2)
  **"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right."**

- Test near vision (80 cm) (FAR #2) with Lenses
  **"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right."**

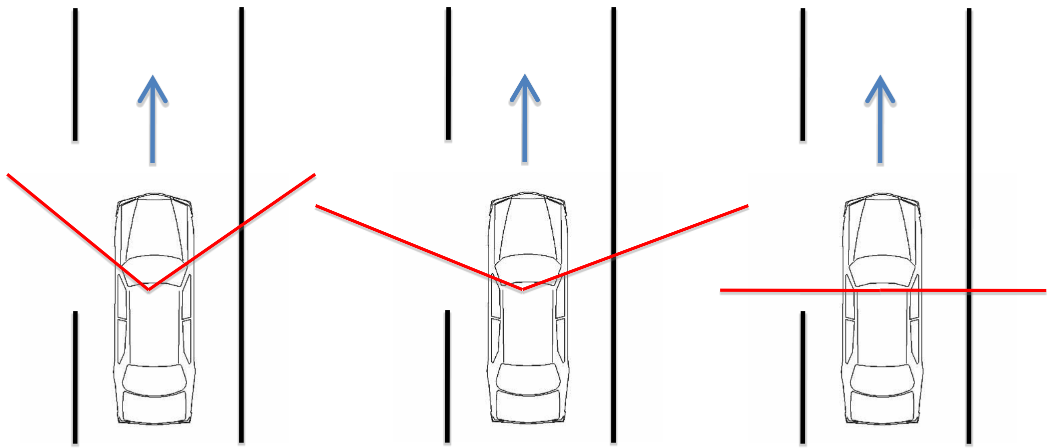
__**Practice Sessions (with 4 cars surrounded)**__

**"This experiment has to do with a single display that will show everything you need to see outside the car. The procedure we are going to use to evaluate display options is not easy to understand, so before that evaluation begins, we need to give you some practice with the method so you are not confused as to what you should do."**

**"In the practice trials, you will see several different designs for this display. The display shows what the driver could see from inside the car. For technical reasons, everything must be shown on a small, single flat display. The goal is to make the driver fully aware of the driving situation, emphasizing what is most important."**

**"For each situation, we may change where traffic appears, how the rear view is shown and how much is shown, and the size of the front field of view. Here is an example of the field of view."**

Show subjects the printout of "field of view 031512_BL.pptx"



120 degree
Field of view

150 degree
Field of view

180 degree
Field of view

**"When driving straight, you need to see is ahead and to the sides. The wider the field of view is, the more you can see. But because the display size is fixed, things ahead are smaller with wider field of view."**

If subjects cannot understand what FOV is, explain to them again or show them the example. The pictures without A-pillar could be used as an example.

**"The rear view will be shown in the rear and side mirrors, with black frames, like this example. Sometimes a rear view camera monitor is used."**

**"For several road scene photos, you will be asked to recall the location of vehicles shown. Draw boxes representing the locations of each surrounding vehicle on a form we will provide. In each box, mark "C" to represent a car and "T" for a pick-up truck. Suppose there were 2 vehicles, a car was 2 car lengths ahead in the left lane and another was a pick-up truck in 1 car length behind, you should mark them like this."**

Show the example. Then have them to practice for the 3 training trials with the order in the random table.

**"OK, after be shown with all the 9 configurations, please rank them from the best to worst in terms of how well they represent the traffic."**

## Experiment

**"We are going to start the main portion of the experiment, which takes 30 minutes to complete. In driving, you need to see ahead, to the sides, and behind you, but not all are equally important for driving down a road. In this experiment, for complex technical reasons, everything needs to be shown on 1 display. The display cannot be too big; otherwise it will block the driver's view. In this experiment we will vary the field of view. The wider the field of view, the more you can see, but because the display size is fixed, things ahead are smaller. We also vary how the rear view is shown."**

Show subjects each image once with the order shown in the "Testing order form.docx". The number of each image is shown in the back. Use the data recording sheet to collect the locations of vehicles that subjects are aware of. Each subject will only have 3 trials in every traffic setting (4 settings, 3 x 4 = 12 for total), which follows the Testing order form.docx.

**"OK. In the 12 images you just saw, the mirror placement, field of view, and the traffic all changed. In the next set of images, the traffic is fixed. Please rank order them from the best to worst in terms of how useful they are to you in representing the traffic situation"**

Show subjects 9 figures in a set (4 sets, A1-A9, B1-B9, C1-C9, D1-D9) and have subjects to rank order.

**Experiment design**

<table>
<tr><td>Traffic settings</td><td colspan="3">2 cars</td><td colspan="3">5 cars</td><td colspan="3">8 cars</td><td colspan="3">11 cars</td></tr>
<tr><td>FOV</td><td>120</td><td>150</td><td>180</td><td>120</td><td>150</td><td>180</td><td>120</td><td>150</td><td>180</td><td>120</td><td>150</td><td>180</td></tr>
<tr><td>No mirror</td><td colspan="3" rowspan="3">Rank A1-A9</td><td colspan="3" rowspan="3">Rank B1-B9</td><td colspan="3" rowspan="3">Rank C1-C9</td><td colspan="3" rowspan="3">Rank D1-D9</td></tr>
<tr><td>Panorama rear</td></tr>
<tr><td>1 Rear + 2 side mirrors</td></tr>
</table>

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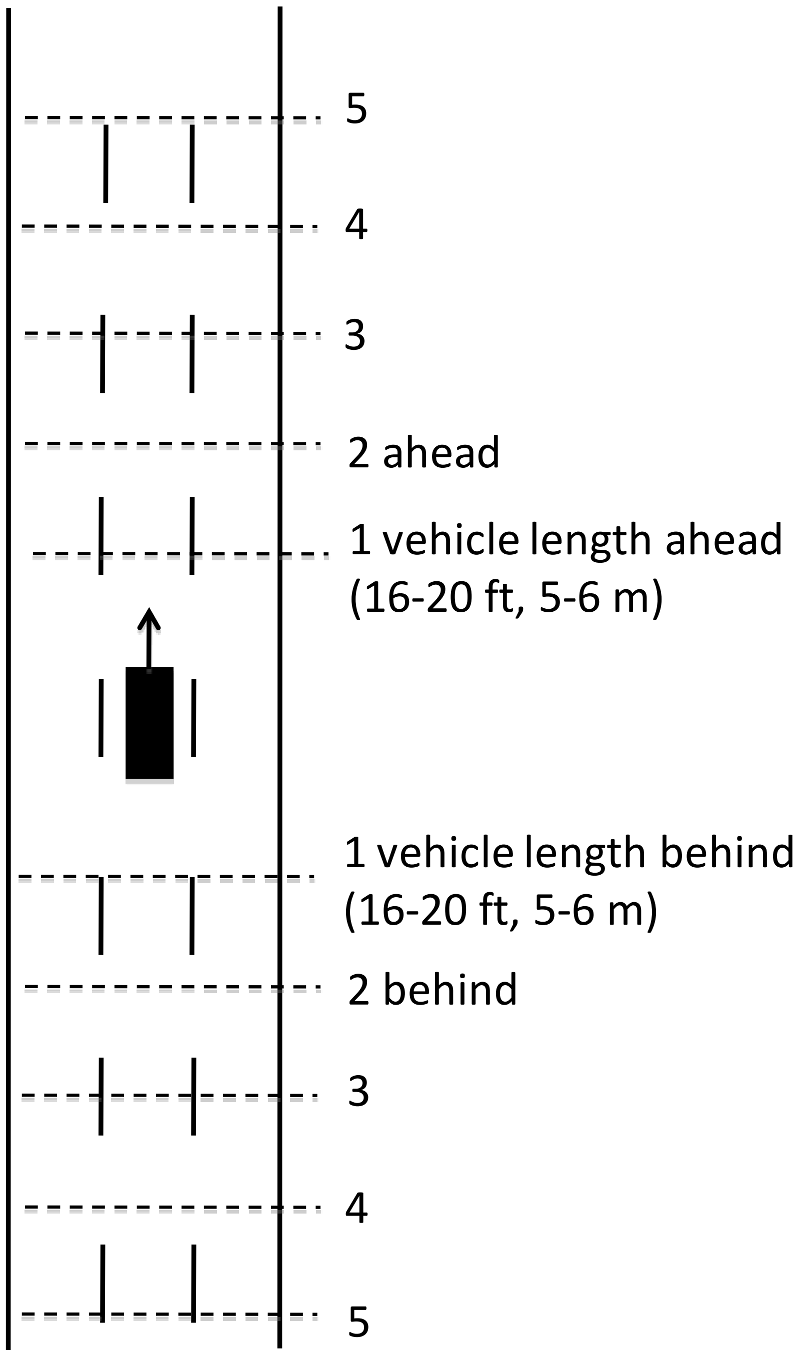
Experiment Data Recording

Draw boxes representing the locations of each surrounding vehicle. In each box, mark "C" to represent a car and "T" for a pick-up truck.

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**<u>Post Test</u>**

**"Great.  We are almost done.  The last part will be filling out the post test form for us."**

Subject filling out the form.

**"Thank you for helping us.  Here is $25.  Please sign this payment form so we can get reimbursed."**

Pay the subjects.  The subject signs the form.

**<u>Subject Wrap up</u>**

- Walk subject to the front door
- Flip sign on door

# APPENDIX M - EXPERIMENT 2 CRAIGSLIST POST

Subjects Needed for Driving Display Study
University of Michigan Transportation Research Institute (UMTRI)

Experiment to assess the usability of a new driving display.
Takes place in a conference room at UMTRI
Licensed drivers, Need subjects from 18 - 65

Takes about 1 hour and pays $25.
Experiment takes place between April 9 and April 20 (Monday through Friday), 9 am - 5 pm
First come first served, times and dates are subject to change
Call Brian

# APPENDIX N - EXPERIMENT 2 PHONE SPIEL

**"We are conducting an experiment to determine how to present the everything the driver could see, to the front, sides, and rear on a single display that will make them fully aware of the driving situation.**

**To determine that, we will have people, maybe you, examine ideas for this display and rank them from best to worst. There is no real or simulated driving, just looking at some ideas for displays in a conference room.**

**To document what we did and your comments, we will videotape the experiment. From those tapes, we will create outtakes to show to the sponsor and the public.**

**The experiment pays $25 for 1 hour and takes place at UMTRI conference room. Are you interested?"**

If yes, record their name, phone number, and email address and schedule a time for the experiment.

**"If you wear glasses when you drive, please bring them as we need to check your vision."**

**"If there is a problem with this date or time, please call me**.