VALIDATION OF THE STATIC LOAD TEST FOR EVENT DETECTION DURING HANDS-FREE CONVERSATION

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Summary: *Objective*. To see if visual event reaction times (RTs) during hands-free conversation conditions in the Enhanced Static Load Test (ESLT) can predict RTs in similar conditions in on-road driving. *Methods*. Brake reaction times to random center and side light events were measured while watching a driving video, attempting to keep a marker in the center of the lane with a steering wheel, answering the phone by pressing a button, and carrying on neutral or angry hands-free conversations in covert (silent) or overt mode on a hands-free phone device. Open-road tests were conducted in traffic for subjects with similar side and front light events, with foot reaction times measured while engaged in the same secondary tasks and conditions. *Results*. Mean RTs for the task segments in the lab were predictive of the mean RTs for the corresponding task segments in the on-road test ($r = 0.90$, df = 16, $p < 0.000001$). *Conclusion*. This study validates the Enhanced Static Load Test as predictive of visual event RTs during open-road driving for the range of experimental conditions and tasks considered.

INTRODUCTION

Numerous approaches have tried to validate driver performance in simulators by using on-road tests (e.g., Blana, 1996; Harms et al., 1996; McGinty et al., 2001; Engström et al., 2005; Yan et al., 2008). Lee et al. (2003) used principal component analysis to find separate performance indices in a simulator and on-road test of 129 older drivers. The simulator and road indices that were combined across variables produced correlations across individual drivers from simulator to road with $r = 0.72$ ($p < 0.05$) after adjusting for age and gender. Lee et al.'s (2003) approach of combining variables to achieve high correlations across *individuals* from lab to road is useful for clinical applications such as determining a particular driver's fitness to drive. A different approach is required in our applied research, which grew out of a need to predict on-road driver performance for *tasks*, rather than individuals, to help improve driver interfaces. We therefore require a test methodology that achieves high correlation across *tasks* from lab to road for single key variables, such as eyes-off-road time, or in this paper, event detection. We typically collapse data across individuals to create a performance metric for each task, for a given variable of interest. We then attempt to predict the on-road metric for each task from the lab metric for each task. In short, we are here interested in predicting on-road tasks, not individuals, from lab data.

As our metric for validation, we use *predictive validity*, defined in two ways: (1) the simulator gives rise to a high *correlation* between the task metrics for lab vs. road; (2) the simulator gives rise to the same *conclusions* about the experimental conditions as the road test. Note that a simulator with *high face* validity (e.g. high visual and dynamic fidelity) does not necessarily ensure *high predictive* validity (Harms et al., 1996; Curry et al., 2005). Likewise, a lab test with *low face* validity can have *high predictive* validity – the Sternberg lab test is apparently unrelated to event detection, but is a good predictor of event detection on the road (Angell et al., 2006). We investigate here the predictive validity of a low-cost, low-fidelity simulator for event detection on the road. Our main metric is mean foot reaction time (RT) to visual events for a set of experimental conditions and tasks related to conversations with a hands-free mobile device.

Static Load Test (SLT)

The first two authors and colleagues previously developed a simple low-fidelity simulator termed the *Static Load Test* (SLT) (Angell et al., 2002; Young et al., 2005). It enhanced the Peripheral Detection Task (PDT) (e.g. Martens & van Winsum, 2000; Harms & Patten, 2003; Jahn et al., 2005) which places a light in a drivers' peripheral vision while they perform secondary tasks. RTs and misses to the light are used as indicators of driver workload. The SLT enhances the PDT by adding a central light far enough away from the peripheral light so that a subject cannot simply stare at one light (or fully direct mental attention to it) without increasing misses to the other light. The SLT also has passive watching of a driving video without steering. Angell et al. (2002) found in a within-subjects design that the SLT had strong correlations ($r > 0.94$, $p < 0.01$) between lab and road across 10 visual-manual tasks for the variables of task time, number of glances, eyes-off-road time, subjective workload and subjective situation awareness. On-road RTs to a visual event for those same tasks and individuals were predicted at $r = 0.72$ ($p < 0.05$), but miss rates were not correlated ($r = 0.5$, n.s.). Young et al. (2005) used a between-subjects design with different institutions and different event detection software for the lab and road tests, but with the same vehicles and tasks. They found no statistically significant correlations for event detection variables across the large number of tasks tested, using mean lab scores to predict 80th percentile road scores. Yet conventional driver workload variables had high lab-to-road correlations for the identical tasks ($r > 0.9$), suggesting something unusual about event detection variables that warranted further investigation.

Young and Angell (2003) did a principal component analysis of a large set of driver performance variable means, for a wide range of visual-manual tasks, using event lights on the hood and side mirror while driving on a closed road. They showed that across tasks, event detection on the road is positively correlated with driver workload variables on the first dimension, but negatively on the second. It is clear from this result that at least two dimensions are needed to account for the contribution of event detection variables to driving performance on the road.

Numerous studies demonstrate that RTs typically increase with conversation by about 200 msec in the lab, and on the road (for review see Horrey and Wickens, 2006). However, previous studies were often separately done on lab, road, or test track with no direct validation of the correspondence (or lack of it) between the domains. We therefore undertook a thorough investigation of the predictive validity for on-road event detection of an enhanced lab test.

METHOD

The *Enhanced Static Load Test* (ESLT) is a stationary lab test of human subjects intended to predict effects on-road driving performance from interacting with in-vehicle systems. It extends the Static Load Test (SLT) described in the previous section by adding a steering wheel by which the subject is required to keep a screen marker in the center of the lane on the driving video (a tracking task, Fig. 1A), adding more visual attentional demand. In addition, the lights presented at central and peripheral locations can now be either red or green. Participants are asked to respond only to the red lights, and to ignore the green lights (a Go/NoGo task).
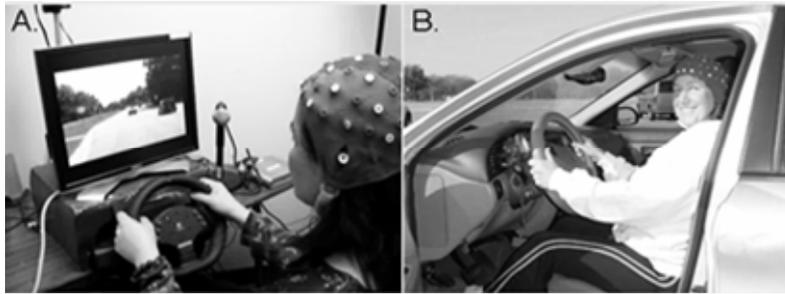

Fig. 1A. Extended Static Load Test in lab B. On-road test

For each trial of the event detection task, a small red or green light event occurs randomly in time, either at the bottom center or left side of a computer monitor showing a high-quality video of a driving scene. When the light is red, the subject is asked to press a pedal with the right foot, simulating a brake response, as soon as an event is detected. Each light terminates after 2.5 sec, or when the pedal is pressed, whichever comes first. The inter-event range is 2 to 5 sec with a mean of 3.5 sec. Events are presented at unpredictable times in the inter-event range to reduce anticipation. The RT and misses to the event lights are recorded. Subjects can direct their eyes and visual attention to any spatial location in the driving scene at will. When a light occurs, it is visible in the central or peripheral field of view for any eye rotation, assuming the eyes are open. In addition, each light is presented to both eyes to ensure it would not be in the blind spot for at least one eye. A light persists long enough (2.5 sec) that it can still be seen either before or after an eye blink. Pressing the brake pedal extinguishes the light. A RT more than 2.5 sec long to the red light is recorded as a *miss*. Simultaneously, a hands-free cellular device is answered by pressing a button after hearing a ring tone, and conversation is carried on with recorded utterances heard through speakers, with verbal responses through the microphone (Fig. 1A). Hits, misses, and brake RTs to the lights on the driving video are recorded by a computer. The ESLT uses custom software for producing behavioral stimuli (lights, sounds), and recording RTs to the lights by pressing the foot pedal.

Fig. 1B shows the vehicle implementation. All event presentation times, response software, and conversation conditions are identical to the lab test. LED lights are placed on the front of the vehicle in the center of the driver's line of sight, and on top of the left outside mirror. The driver responds to the lights with the left foot, pressing a switch to the left of the brake pedal (using the brake to respond to the lights might have interfered with driving). Training was done while stationary before the experimental run. All road subjects were previously run in the lab, to ensure familiarity with the protocols. The road test was on an open highway with traffic (Route 23 near UMTRI in Ann Arbor), which has a speed limit of 65 MPH. There was an experimenter in the front seat with a secondary brake pedal as a precaution but no incidents occurred.

Subjects

Subjects participated on a voluntary basis, provided written informed consent, and were compensated. Human subject protocols were approved by the respective human subject committees at our universities. Subjects had to be unfamiliar with the system under investigation, interested to use the system, capable of learning and completing the test procedure, and have no physical limitations that would affect task performance. The sample (obtained through ads) was evenly split between genders, from ages 21 to 65 inclusive. Each subject practiced trial tasks until successful (with feedback or instruction prior to formal testing). In the lab tests, 23 subjects participated for covert conditions, and 17 other subjects for overt conditions. In the road test, all 16 subjects were run in all conditions, and all these subjects were previously in a lab test.

Experimental Conditions

The experimental conditions were the same for the lab and on road, with event detection and driving (or simulated driving) for all conditions. Conversation conditions occurred with a hands-free cellular device with three main conditions: (1) no conversation (baseline); (2) neutral conversation; and (3) angry conversation. Subjects were called several times while engaged in the driving or simulator task. After hearing a ring tone, they answered a call by pressing a button with their right hand. The subject was asked various simple autobiographical questions in an angry or neutral tone. *Covert* (speaking to oneself) speech responses were intermixed in a balanced manner with *Overt* (speaking aloud) speech responses for the neutral and angry conditions. In the lab, there was a fixation baseline with a crosshair on a blank screen between the main experimental conditions.

Performance Metrics, Task Segments, and Statistical Methods

The main objective was to determine the lab-to-road predictive validity of the ESLT for event detection. The major event detection metric was the foot RT to a red light event. (There were few misses under any condition.) The behavioral data were split post-hoc into 18 task segments for correlation analysis. For ease of labeling the points in a graph, the task segments can be viewed as arising from a 2 x 4 x 2 experimental design: variable one with two levels - *Covert* and *Overt*; variable two with four levels - *Neutral* conversation, *Angry* conversation, *Button* press, and *No speech* (RTs in gaps between conversations within a conversation session, determined post-hoc); and variable three with two levels - *Left* or *Center* light position. The remaining two task segments came from the baseline condition, by dividing it into Left and Center light responses.

The foot RTs were averaged for each subject for each task segment, to create a subject mean for each segment, paired for lab and road. (Missed lights were excluded from the RT means, but there were so few missed lights that their exclusion did not influence the results.) We employed simple linear regression and correlation methods, as per our earlier studies validating lab-road correspondence (Angell et al., 2002, 2006; Young et al., 2005). A Pearson correlation coefficient was formed across the paired task means for lab and road. The statistical significance of the correlation coefficient was tested by a *t*-test with 16 df. ANOVAs were also conducted in separate analyses for lab and road, covert and overt, to see if similar conclusions about the road data would be reached if only the lab data had been available.

RESULTS

Fig. 2 shows a strong correlation between the lab and road RT task segment pairs ($r = 0.90$, $t = 9.03$, df $= 16$, $p < 0.000001$). Discarding the four longer RT button tasks (9, 10, 17, 18) still gave rise to a statistically significant correlation ($r = 0.71$, $t = 4.93$, df $= 12$, $p < 0.001$).

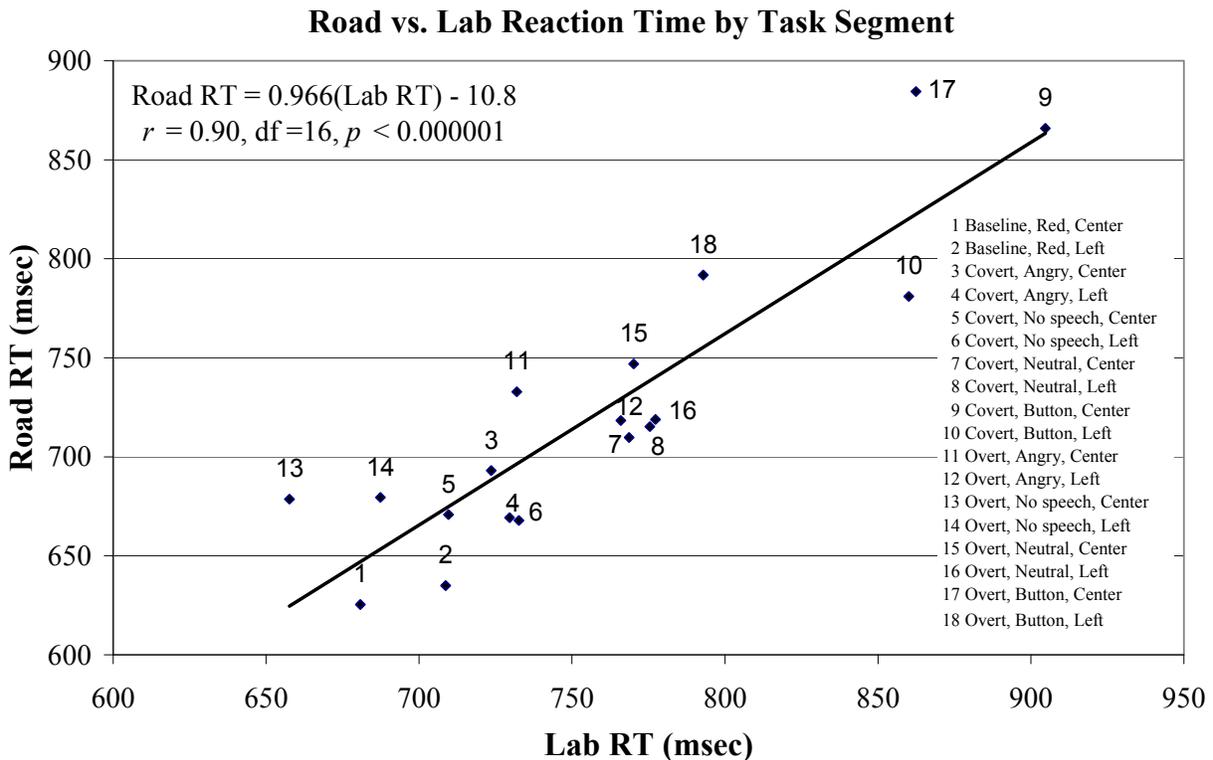**Road vs. Lab Reaction Time by Task Segment**

Figure 2. Mean brake RT across subjects for each task segment, comparing lab (x-axis) vs. road (y-axis). The 18 task segments are labeled in the inset table

We conducted two-way within-subject ANOVAs on lab RTs for Overt and Covert speech conditions. Results show a main effect of conversation (Baseline vs. Neutral vs. Angry) for both Overt ($F(2,101) = 35.40$, $p < .001$) and Covert ($F(2,126) = 12.0$, $p < .001$) speech. Separate ANOVAs on the road data found the same main effect: Overt ($F(2,75) = 37.9$, $p < .001$) and Covert ($F(2,75) = 16.5$, $p < .001$). Also, mean RTs during the Button press task were larger than any conversation mean RT, for both lab and road, as is obvious by visual inspection of Fig. 2 (points 9,10,17,18). In sum, if only the lab data had been available, the same main effects would have been found as if the study had been run on the road. The only exception was a slight effect of light position (Left vs. Center) in the lab, that was not statistically significant on the road.

In short, hands-free cellular device conversations caused small (about 100 msec) but statistically significant RT increases for visual event detection compared to a baseline with no conversation, with even larger RT increases for a single button press. These results were the same in the lab as on the road. There were few errors (failure to respond to the red light, or an incorrect response to the green light) in the lab or on the road, and these will be separately reported.

DISCUSSION

This study found a correlation of 0.9 for event detection RTs using the Enhanced Static Load Test for conversation-related task segments compared to data from a road test with the same task segments. This correlation is higher than found in prior studies of event detection RT (Angell et al., 2002, 2006; Young et al. 2005) – though prior studies examined broader sets of tasks with more variation in task type. Nonetheless, for the first time, the ESLT brings lab-to-road correlations of RTs to the strong levels found for major driver workload variables such as eyes-off-road time (Angell et al., 2002, 2006; Young et al., 2005). Thus, the ESLT offers promise as a laboratory surrogate for event detection measures as well as driver workload variables.

The slight increases in foot RT for conversation vs. baseline are consistent with studies previously conducted in lab or on road alone using similar event detection methods (e.g., Schreiner et al., 2004; Bowyer et al., 2007, 2008, 2009; Hsieh et al., 2009). Our similar pattern of RT effects for covert and overt speech is consistent with lab studies during MEG brain imaging (Bowyer et al., 2008). The relatively larger increases in RT for the visual-manual button press task to answer the cellular device indicates the importance of separating the visual-manual aspects of calls (e.g., dialing, answering) from the conversation aspects, as per Klauer et al. (2006). The finding that visual-motor tasks give rise to longer RTs than voice tasks also supports the conclusions of Angell et al. (2006) who used a wider variety of visual-manual and auditory-vocal tasks. The finding that the miss rate for events during conversation tasks was low confirms Angell et al. (2006) and Schreiner et al. (2004), and is important in its own right.

Real-World Implications

A recent real-world epidemiological study (Young and Schreiner, 2009) compared personal conversation crash rates to no-conversation crash rates using a hands-free wireless device "embedded" or built into the vehicle. This study found no increase in airbag-deployment crash rates for personal conversations using the device, compared to driving without conversing on the device, consistent with the low crash risk found by Young (2001) for calls to an OnStar advisor.

Why is the increase in RT during hands-free conversation in experimental studies not associated with an increase in real-world crash rates when using a hands-free embedded device? Young and Schreiner (2009) hypothesize that the low crash risk in their real-world study "can be explained if drivers making personal wireless calls using the OnStar embedded hands-free calling device are taking responsibility to: (1) make prudent and safe choices about engaging in calls during adverse road, environmental, or traffic conditions, (2) reduce or postpone elective driving maneuvers or secondary tasks that might increase crash risk when in a call, and (3) adapt conversations while in a call to accommodate road and traffic conditions." Drivers might also be compensating for the predicted small RT increases from hands-free conversations using this device by simply taking extra care to keep their eyes on the road, hands-on-the-wheel, and mind-on-the-drive. Real-world in-vehicle naturalistic observational studies such as that of Klauer et al. (2006) will likely be necessary to determine exactly how it is that drivers may be compensating for these predicted RT increases, to keep their crash risk at normal levels.

CONCLUSION

This study validates the Enhanced Static Load Test as predictive of visual event RTs during open-road driving for the range of experimental conditions and tasks considered.

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