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Engineered Visibility Warning Signals: Tests of Time to React, Detectability, Identifiability and Salience

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation was completed as part of the ITS-IDEA Program which is one of three IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in surface transportation. It focuses on products and result for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan. The other two IDEA programs areas are Transit-IDEA, which focuses on products and results for transit practice in support of the Transit Cooperative Research Program (TCRP), and NCHRP-IDEA, which focuses on products and results for highway construction, operation, and maintenance in support of the National Cooperative Highway Research Program (NCHRP). The three IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods and technologies, including conversion technologies from the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems.

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EXECUTIVE SUMMARY

INTELLIGENT TRANSPORTATION SYSTEMS (ITS) PRODUCT

A new feature of in-vehicle visual warning signals has been designed and tested. Such signals are necessitated by the accelerated sensory demands upon the ITS driver due to the technological assistance promised by ITS systems. The new feature is designed to optimally stimulate the visual nervous system if used in a Head-Up Display (HUD) as is widely predicted, or even in head-down applications. The new design feature employs motion in the warning signal with the result that signals are seen more quickly and more accurately. This feature is a product in the sense that its use may be licensed from the Office of Technology Licensing of the University of California, Berkeley. Its use should enable designers to upgrade warning signals intended for ITS applications.

CONCEPT AND INNOVATION

The central product is a feature of an advanced visual display for warning signals. Signals using this feature are termed "Motion Enhanced Warning Signals" (MEWS). The product can be implemented in either head up or head down configurations. Its specific use in design is based upon the literature on vision and human factors research pertinent to the detection and identification of warning signals. Our initial tests of the MEWS prototype display show that we have achieved marked advantages in time to react, identifiability salience, and detectability. The subsidiary products of this study include (1) a generic testing system that will allow designers to test their own, presumably improved, designs (employing the MEWS feature) and to compare the performance of their design to that of ours, and (2) guidelines for designers that cite the salient features of vision and human factors research that bear on the process of design and which include benchmark measurements for our design.

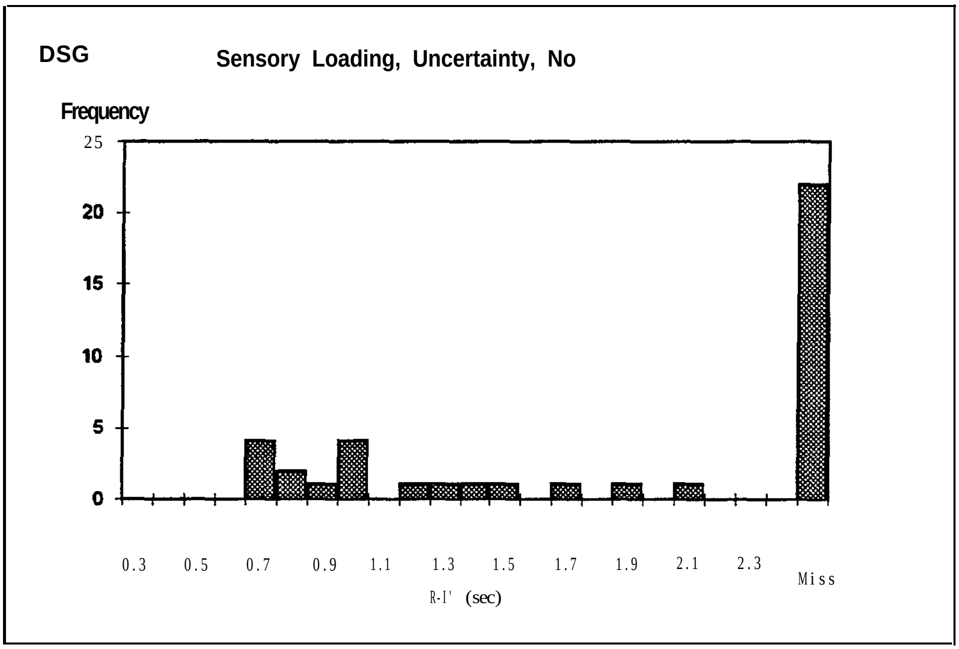
PROJECT RESULTS

The IDEA investigations had several objectives. The first was to obtain evidence ("proof of concept") that could either support or refute the idea that motion which is used in MEWS enhances signal detectability, identifiability, time to react and salience. The next objective was to develop written Guidelines that would enable designers to develop their own designs. The third objective was to develop a warning signal testing system that can readily be used by designers to test their own designs. The final objective was to obtain benchmark measurements on a small sample of typical drivers to which designers can compare the measurements that they obtain on their own designs.

The proof of concept tests directly compared the MEWS design with conventional stationary warning signals. The comparison warning signal was a circular spot with a Gaussian intensity profile (std. dev. = 9.2 Arcmin). The test (MEWS) signal was one such spot, ignited at a given position for 100 msec , extinguished, and then followed 10 msec later by another adjacent identical ignited spot. This gives the target signal "apparent motion". Onset of the stimulus can be sudden (rise time < 1 msec) or gradual (rise time about 250 msec approximating the behavior of a tungsten filament). This comparison warning signal is rather like telltales presently in use that ignite over a discrete area at a particular dashboard position. That choice simplifies the test. The only exemplary feature of the test signal was its motion, Motion was the only difference between it and the comparison signal, their maximum contrast being the same.

Image contrast for the subsequent trials is first determined by an adaptive trial and error procedure which determines the contrast (termed "threshold contrast") that can be seen about 80% of the time. Subsequent trials use this value of contrast for both stimuli in the time-to-react tests. Hence the integrated intensity is nearly the same for these two warning signals. Correctness and time of response are recorded on each trial. Fixation of gaze can either be at the location of the target or peripherally by 9.1 deg. In a variant of this procedure, the comparison or test stimulus can be positioned at one of four locations defined by the ends of a steadily illuminated "X" whose arms extend 4.2 deg. in length. In this case fixation can also be peripheral or at the X intersection.

Figure 1_{ES} shows the distributions of reaction time (RT) for one observer for a peripherally imaged target. These are representative of the results for other subjects. The upper distribution is for trials on which the target was stationary. The lower distribution is for trials on which the target was placed in apparent motion. Motion gives the lowest values of RT observed. Also, the distributions are different in character, with the stationary stimulus having twice the variance in RT. obviously, many extra long RT's occur for the stationary stimulus and the difference of the average RT (277 msec for this observer) only begins to convey this. A 277 msec delay in reaction to a warning signal at highway speeds (88 feet/sec) puts a vehicle 24 feet further down the road before the driver completes his/her reaction. The design of this test suggests that this difference is due solely to the motion in the warning signal. At the same time, there is also a difference in the accuracy of judgment in that stationary targets are missed (responses not included in the RT calculation) much more often than those in motion. Table I_{ES} summarizes the advantage, in **RT expressed** in msec , and the advantage in detectability (d') that we measured by task.



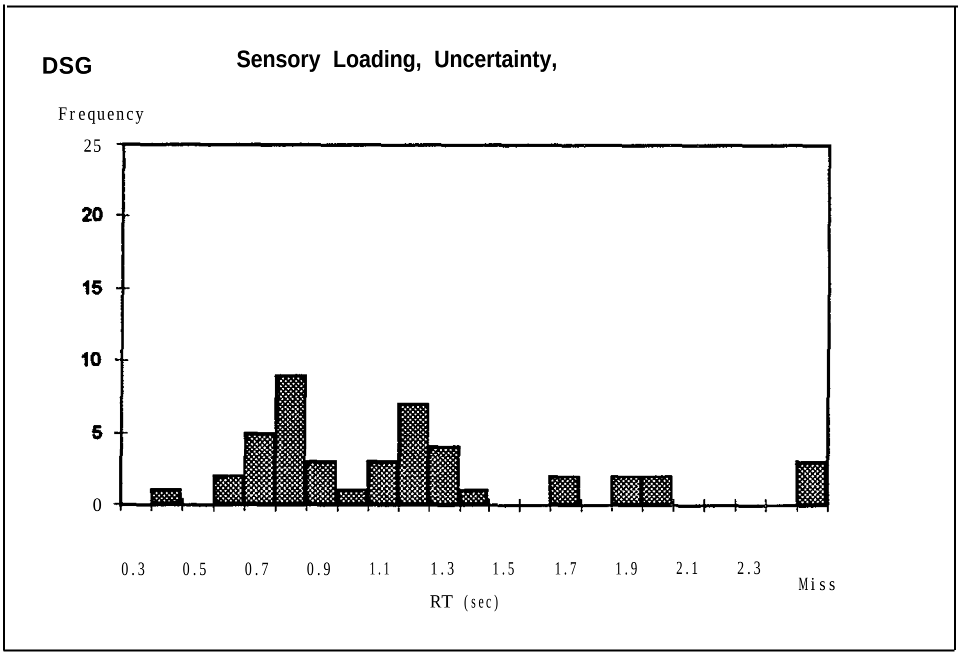


FIGURE 1_{ES}. Time-to-react histograms when an observer is uncertain as to the warning signal to be detected and while engaged in a task similar to vehicle guidance with (below) and without (above) motion.

TABLE I_{ES}. Reaction Time Improvement With MEWS

Task	Average RT Improvement	Average d' Improvement
Simple Detection - Fovea	69 msec	not measured
Simple Detection - 9 deg.	276 msec	1.24
1 of 4 Detection Periphery	236 msec	1.39
1 of 4 Identification	277 msec	1.63

If one is looking right at the location of a warning signal target (the ideal condition for perception) there is still an advantage to having the target **move,** even though it is thought that the central area of vision relies less on motion pathways and more on color and fine detail signaling. The advantage of movement goes up, when viewing is peripheral, when the task is more complex (as in a 1 of 4 detection task), and when the task requires additional cognitive effort (identification).

We have completed tests with distracting elements present in the field of view and tests in which the observer is performing a guidance task comparable in sensory load to vehicle steering. In both cases we find a significant advantage for the MEWS warning signals. These results suggest that MEWS warning signals have superior salience to standard motion-free warning signals

Warning Signal Display

The warning signal display has been fashioned to be compact and intelligible as well as having other desirable visual features. Our design can be improved but the MEWS feature is essential to approach an optimal design. A stimulus to accommodation which conveys a sense of coordinates within which to interpret warning signals is also important.

Visual stimuli need to be positioned in logical relation to the action required; this in turn suggests the use of a vehicle icon to define the logical space in which the signals can arise. A continuously-present vehicle icon makes the coordinates explicit and also supplies a needed cue to accommodation. In addition, it is desirable for warning signals to be dissimilar in shape, to occupy non-overlapping positions, and to be small enough to keep the display as a whole under nine visual degrees wide or high while at the same time large enough to be well beyond the acuity limit. Figure 2_{ES} shows a preliminary sketch of the vehicle icon reference signal and cue to accommodation accompanied by examples from the six possible MEWS warning signals: (a) emergency vehicle ahead — the icon jumps from side to side, (b) too fast for curve ahead — the curved arrow is placed in apparent motion, (c) icy roadway — wavy lines march across from left to right, (d) too fast for stop-sign ahead — the stop sign expands or "looms", (e) disabled vehicle ahead — the vehicle is in motion and "looms" toward the observer, (f) train in railroad crossing ahead — the railroad ties are placed in apparent motion.

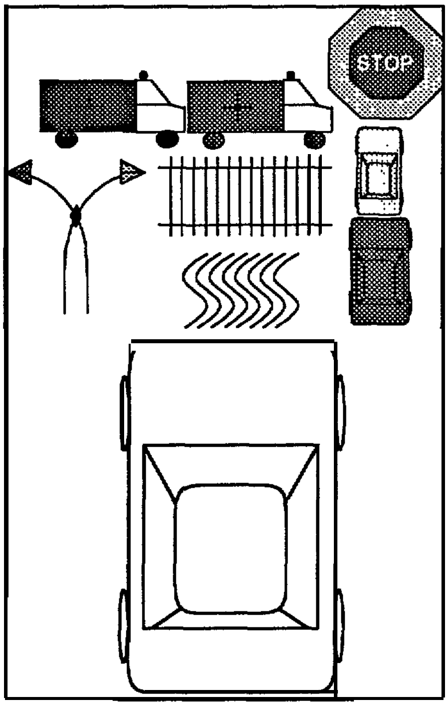


FIGURE 2_{ES}. Composite sketch showing all six MEWS warning signals.

Testing Facility

The test facility that we have used for the experimental work has been structured to be readily adapted for use in other laboratories. It includes a 486 PC compatible, a Cambridge Research Systems (crsltd@crsltd.demon.co.uk) VSG/2 Frame store, and a Sony 20SE computer monitor. The sofhvare includes routines supplied by Cambridge Research Systems and Visual Basic code developed for the project.

Guidelines

The guidelines include: a discussion of the relevant attributes of the visual nervous system; a description of a testing system including both software and hardware, benchmark measures of performance (including warning signal detectability, identifiability and time to react); and extrapolated performance measures for a fully implemented system.

The application of this new technology to ITS warning signals does not require simulator or prototype testing. This is because the idea developed here relates solely to the way in which visual signals meet the eye. Other elements of the warning signal system, such as the sensors to activate it, the rules that they obey, optical distance from the observer etc. are all independent of the MEWS concept. Discrete element dashboards, scanned arrays or CRT-based HUD displays can be fitted with MEWS warning signals which can improve their performance.

DESCRIPTION OF PROJECT

ITS PRODUCT

A new feature of in-vehicle visual warning signals has been designed and tested. Such signals are necessitated by the accelerated sensory demands upon the ITS driver due to the technological assistance promised by ITS systems (M. J. Paley and D. I. Tepas, 1994). The new feature is designed to optimally stimulate the visual nervous system whether used in a Head-Up Display (BUD) or in head-down applications. The new design feature employs motion in the warning signal with the result that signals are seen more quickly and more accurately. This feature is a product in the sense that its use may be licensed from the Office of Technology Licensing of the University of California, Berkeley; its use of should enable designers to upgrade warning signals intended for ITS applications.

CONCEPT AND INNOVATION

The central product is a feature of an advanced visual display for warning signals. Signals using this feature are termed "Motion Enhanced Warning Signals" (MEWS). The product can be implemented in either head up or head down configurations. Its specific use in design is based upon the literature on vision and human factors research pertinent to the detection and identification of warning signals. Our initial tests of the MEWS prototype display show that we have achieved marked advantages in time to react, identifiability, salience, and detectability. The subsidiary products of this study include (1) a generic testing system that will allow designers to test their own, presumably improved, designs (employing the MEWS feature) and to compare the performance of their design to that of ours, and (2) guidelines for designers that cite the salient features of vision and human factors research that bear on the process of design and which include benchmark measurements for our design.

PROBLEM STATEMENT

ITS planning, and the advances contemplated in Advanced Traveler Information Systems (ATIS), promise a heavily increased level of information flow to vehicle operators in the future (IVHS, 1992; M. J. Paley and D. I. Tepas, 1994). Some of this information will be in the form of warning signals, possibly as many as a dozen new ones. For this reason it is important to examine the optimal means of presenting these to the human observer. Many planners agree that the most likely embodiment of such signals will be in head-up displays. If so, new issues arise such as the appropriate optical distance from the observer, the inevitable loss of contrast in HUD configurations and the clutter of distracting elements also present in and around the visual region of the display.

This project was designed to examine a focused set of questions surrounding this conception of the future. The first question is the most important: will the visual apparatus of the typical human observer be able to correctly handle up to a dozen new warnings? The next several are also important: can such signals be fashioned to match the capabilities of the human visual nervous system? Are there means of circumventing the contrast loss inherent in head-up viewing? Will a solution benefit the entirety of the vehicle operating public or only a subset?

Goals of the project include obtaining, experimentally, answers to all but the last of the foregoing questions. in addition we aimed to develop a transportable and replicable testing apparatus and method that display designers could use to test their own designs, plus a written set of guidelines to assist display developers in their efforts.

AN INNOVATIVE IDEA

The recent vision and human factors literature has provided increasing evidence that two visual systems operate in parallel. The M system codes fast time varying visual signals and especially movement. It doesn't code fine spatial detail or color but has better contrast sensitivity and faster responses. The P system, on the other hand serves the purpose of coding color and fine detail in the retinal image, but it does so with poor contrast sensitivity and speed. Given this dichotomy it seemed prudent to present warning signals that preferentially stimulate the M system, thus taking advantage of speed and sensitivity and its indifference to detail.

Accordingly we have developed a system of visual warning signals that are designed to optimally stimulate the M system. The unique and innovative quality of these warning signals is that they employ motion[1] and they are ***thus*** termed ***motion enhanced warning signals (MEWS).*** Further, we developed a test system to examine the validity of this idea, and have developed guidelines intended to help designers employ these ideas.

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[1]Use of motion in signaling is not without precedent. Its use, particularly for peripheral viewing, has attracted attention in the past (Majendie, 1960; Fenwick, 1963; Vallerie, 1988) even though the physiological basis for this choice, and its implications for target detail requirements were not known.

RESEARCH APPROACH

DISPLAY IMPLEMENTATION

We developed a flexible system with which to implement displays by employing advanced computer based image generation equipment. It was important that such a system be replicable so that commercial developers could assemble an equivalent system for testing their designs. The heart of the system is an advanced framestore that occupies one slot of a 486 (or higher) IBM PC compatible (Cambridge Research Systems VRG/2). The framestore is capable of driving a high definition non-interlaced color monitor as fast as 150Hz, allowing the apparatus to emulate **even** rapid turn-on solid state devices such as LEDs. We employed a Sony 20SE monitor for our study. The Cambridge framestore is associated with a library of software routines supplied by the manufacturer. To these we have added Visual Basic code designed to allow implementation and testing of the MEWS warning signal design. A description of the software will be found at a Web site (http://www-.PATH.eecs.berkeley.edu).

DISPLAY DESIGN

Our reading of the human factors literature made it clear that a viable warning signal system required a continuously present cue to accommodation (M. L. Matthews, R G. Angus, and D. G. Pearce 1978). Such a cue, if properly configured serves an equally important cognitive purpose, that of supplying a coordinate system within which to interpret the warning signal. We chose a plan view of a vehicle icon (in the form of an outline, Figure 1). Warnings of incipient events are all developed within, and in relation to, the space defined by this icon. For example, a vehicle malfunction such as might occur for tires or engine is represented at or near the appropriate part of the icon. A hazard to the side of the vehicle appears to the side of the icon, one ahead appears above, and so **on.**

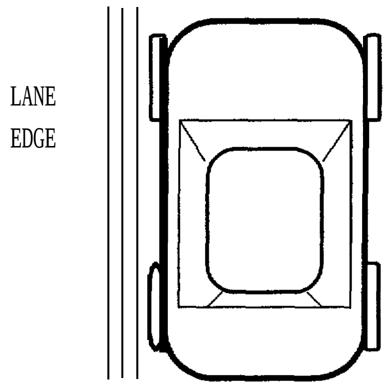

FIGURE 1. Vehicle icon that serves as a cue to accommodation and which defines a coordinate system within which to interpret warning signals, plus elements of a MEWS warning signal to indicate "too close to lane edge".

While not common to warning signal design, and not the original intended subject of examination of this study, the innovation of the cue to accommodation provides a significant advantage in the effort to optimize warning signal performance.

DESIGN OF MOTION ENHANCED WARNING SIGNALS

Figure 1 also shows an example of a MEWS warning signal that we have developed (in a separate study) to signal the encroachment on a lane edge. Two parallel stripes next to the vehicle icon are ignited in sequence. The result is a single stripe that appears to move toward the icon. The reader will appreciate that the only aspect of this design that can be considered optimal is the inclusion of the motion feature (MEWS signaling). The graphic and artistic aspects of the design are primitive and it would be expected that a competent designer could produce a superior "look."

Other MEWS warning signals employed in this study include a) railroad crossing occupied ahead (b) encroaching vehicle in intersection ahead (c) stopped vehicle in road ahead (d) emergency vehicle ahead, (e) too fast for curve ahead, and (f) too fast for stop sign ahead. The project was reconfigured on the advice of our advisory committee to examine the six warning signals which were chosen by committee members to reflect warning signals they felt would be implemented in the near future.

TEST METHODS

The purpose of proof of concept tests was to determine if motion in a warning signal will improve detectability, salience, and time to react. The comparison warning signal was a circular spot with a Gaussian intensity profile (std. dev. **= 9.2** Arcmin). The test signal consisted of one such spot, ignited at a given position for 100 msec, extinguished, and then followed 10 msec later by another adjacent identical ignited spot. This gives the target signal "apparent motion". Onset of the stimulus could be sudden (rise time < 1 msec) or gradual (rise time about 250 msec approximating the behavior of a tungsten filament). This test warning signal is rather like telltales presently in use that ignite a circular area at a particular dashboard position. The test was designed to be as simple as possible with the only difference between the test signal and the comparison signal being the apparent motion of the former,

Trials were run with the test image, and the comparison image, set to the threshold contrast. This was determined by an adaptive trial and error procedure that estimated the contrast which would be seen about 80% of the time (termed the 'threshold contrast'). Subsequent tests use this value of contrast for both stimuli in the time-to-react tests. Hence the integrated intensity was roughly the same for these two warning signals since each had the same maximum value. The test stimulus was actually slightly less in integrated intensity since, in most trials, it was "off" for a 10 msec period during each 210 msec segment, and was also off for 100 msec between segments. The comparison stimulus was on steadily during this period.

Comparison and test stimuli were randomly interleaved in a block of 50 trials. On each trial the observer called for a stimulus by a button push. There ensued a delay period of 0.5 sec followed by a period during which one or the other stimulus could occur at one of six times (0.0, 0.35, 0.95, 1.97, 3.7 or 5.5 sec) or no stimulus could be presented. The non-uniform stimulus time distribution, roughly an exponential, was chosen to minimize subject anticipation. The observer's task was to respond with a button push upon detecting a stimulus. Correctness and time of response were recorded on each trial. Fixation could either be at the location of the target or peripherally by 9.1 deg. In a variant of this procedure, the comparison or test stimulus could be positioned at one of four locations defined by the ends of a steadily illuminated "X" whose arms extend 4.2 deg. in length. In this case fixation could also be peripheral or at the center of the X.

RESULTS

Eleven separate experiments were conducted. They include four of the originally proposed seven experiments (I, II, III, and VI,) plus seven new experiments to replace original experiments IV, V and VII. All are listed below grouped by the subject groupings of the original seven. They will be discussed in the following order:

A. Proof of Concept
   1. Detection of one signal **(added** to project scope)
   2. Detection of one signal, effect of contrast **(added** to project scope)
   3. Detection of 1 of four equally likely possible signals **(added** to project scope)
   4. Identification of 1 of four equally-likely possible signals **(added** to project scope)

B. Experiment I-II (each of the following done under both day and night conditions)
   5. Detection of one signal, each of six signals studied
   6. Detection of one of six possible signals
   7. Identification of one of six possible signals

C. Experiment III-IV
   8. Detection of one signal with sensory loading
   9. Detection of one of four signals with sensory loading

D. Experiment V, VI, VII
   10. Effect of distractors on simple detection **(added** to project scope)
   11. Effect of distractors on one of four detection **(added** to project scope)

Tables referenced in the following sections can be found in the appendix.

PROOF OF CONCEPT TESTS:

The proof of concept tests directly compared the MEWS design with conventional stationary warning signals.

1A. Simple Detection

Conditions for this test were as follows:

Experiment 1A. Detecting a single target viewed peripherally				
Task	Fixation	Lighting	Viewing	Target Shape
Simple Detection	4.2 deg.	Day	Head down	9.2 Arcmin Gaussian

Figure 2 shows histograms of measured time to react for a single target. These are representative of the results for other subjects, and they serve to reveal the main themes conveyed by the data in our study. The upper distribution is for trials on which the target was stationary. The lower distribution is for trials on which the target was placed in apparent motion, where the lowest values of RT were observed. Also, the distributions are different in character, with the stationary stimulus having twice the variance in RT. Obviously, many extra long RT's occur for the stationary stimulus and the difference of the average RT (277 msec for this observer) only begins to convey this. A 277 msec delay in reaction to a warning signal at highway speeds (88 feet/sec) puts a vehicle 24 feet further down the road before the driver completes his/her reaction. The design of this test suggests that this difference is due solely to the motion in the warning signal. At the same time, there is a difference in the accuracy of judgment in that stationary targets are missed (responses not included in the RT calculation) much more often than those in motion.

The key feature for planners is the existence of times to react, that fall far above the usual range when the non-MEWS target is employed. We refer here to reaction times that exceed the mean by some criterion amount. It is those events that are troublesome to both designer and planner because they represent instances when, conceivably, the warning is not seen as fast as it could be, leading possibly to a safety problem. MEWS targets yield far fewer of these.

Table I summa&es the average advantage, in msec , and the advantage in detectability (d') that we measured for this task. Data are shown for each of three subjects. The average reaction time is computed for reaction times that fall within 2.5 sec of the stimulus onset. This introduces a conservative bias into our analysis by eliminating all trials on which the stimulus was missed. For subject, BLG, the miss rate for non-moving targets was 21% while for the MEWS it was only about 6%. Included in this data summary table are measures of the spread of reaction times when the target wasn't missed (revealing larger value for non-MEWS targets). The reader will note that times to react are generally quite large, far larger than the fastest times reported by other investigators. This is due to our choice to conduct the experiment at or near threshold contrast. We have centered our attention on this condition, when targets are hard to see, because that is where warning signal qualities are most amplified. It also reveals more about what is likely to happen when the human observer is pushed to his limits, a condition where warning signal efficacy is of the most importance. When targets are easier to see, times to react decline appropriately (see below).

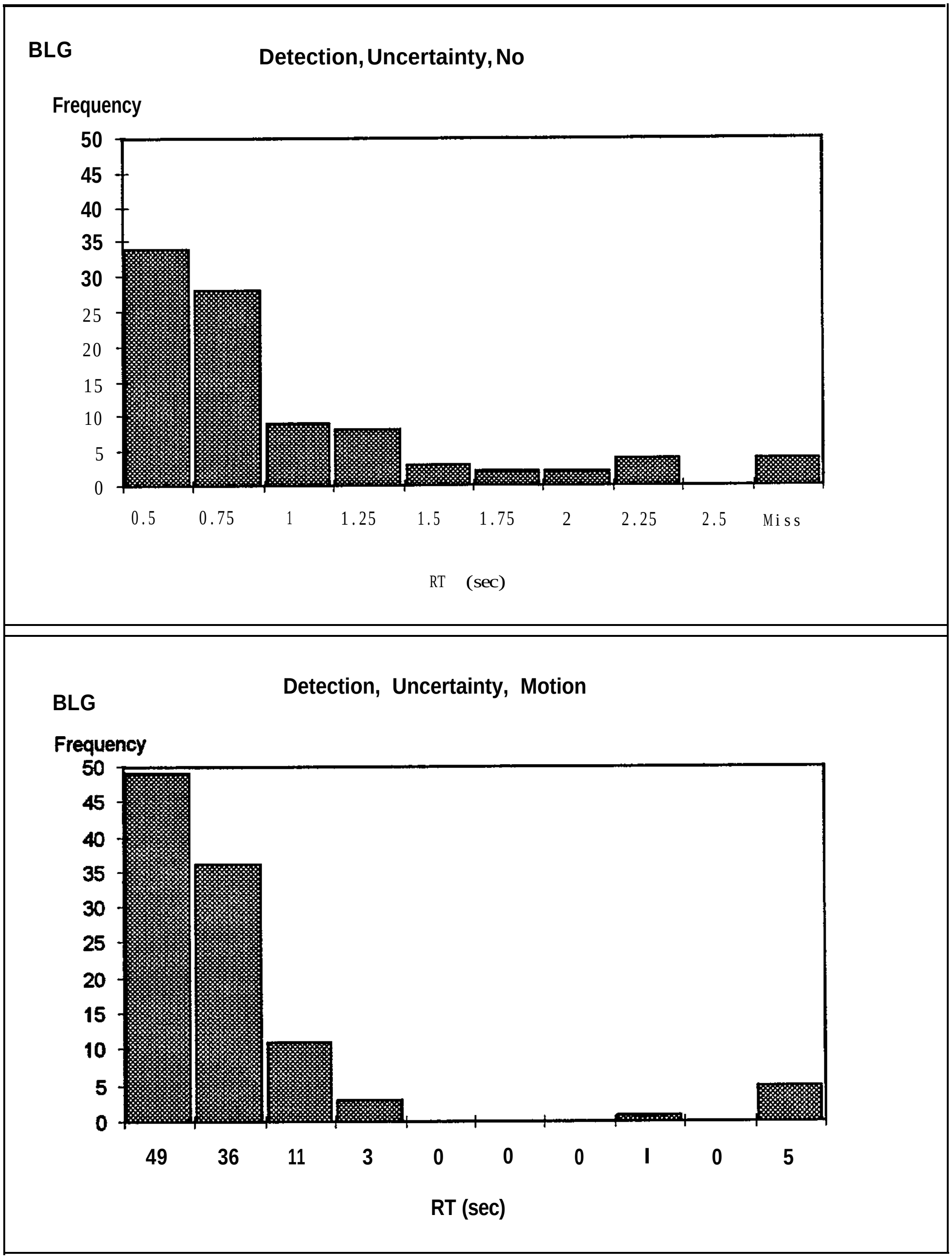

FIGURE 2. Frequency distributions of time to react for simple detection with (below) and without (above) motion.

Another very important feature of these data is the variability that they exhibit. This is clear in the histograms. Even though the stimulus is physically fixed, the response to it is highly variable, occurring over a range of times following stimulus onset and including occurrences of detection and of miss, of correct rejection and of false alarm. This is not due to an imperfection of human subjects so much as it is due to the nature of detecting threshold stimuli. Individual differences that appear in our data tables may, to a large degree, be due to the inevitable sampling error that occurs in threshold situations. That is a weakness of our experimental approach, but this cost enables us to quantify human performance in the most trying of conditions, when the target is hard to see.

The measure termed d' is the target detectability. This is a value which should be the same for both targets since their integrated energy is nearly the same. Detectability clearly favors the MEWS signal; it is easier to see. Hence, at an appropriately chosen lower contrast, it would be seen just as often as the non-MEWS signal.

1B. Simple Detection with Foveal Fixation

Conditions for this test were as follows:

Experiment 1B. Detecting a single target viewed foveally				
Task	Fixation	Lighting	Viewing	Target Shape
Simple Detection	foveal	Day	Head down	9.2 Arcmin Gaussian

This experiment was identical to the first one, except that observers were allowed to look at the spot where the target would be imaged. The advantage for MEWS signals proved to be less than for peripheral viewing. For three subjects, a reaction time advantage of MEWS signals was 85, 58 and 65 msec , averaged 69 msec . The explanation for this difference is probably to be found in a reduced sensitivity to motion in the fovea, where targets were imaged. These results are less pertinent to practical warning signal situations because it will be rare that the observer is looking at the warning signal locus before its arrival.

2. Detection of one signal, effect of contrast

(Conditions as for Experiment 1A).

It is well reported in the human factors literature that time to react is a strong function of contrast. We examine this phenomenon for both MEWS and non-MEWS stimuli in order to explore further the nature of the MEWS advantage in detectability. We systematically changed stimulus contrast and measured the usual outcomes. Figure 3 reveals the relation between time to react and stimulus contrast; there is a systematic decline in time to react with contrast. In fact average values as low as 0.3 sec have emerged in our study at contrasts only 3X threshold. This value is quite close to the best reported for even more suprathreshold targets. Interestingly, even though the time to react declines, the advantage for MEWS targets persists as roughly a fixed fraction of the average value for the non-MEWS target. Table II summarizes results of this experiment for two subjects. At threshold, MEWS targets are seen on average 206 msec more quickly by BLG and 81 msec more quickly for IAT

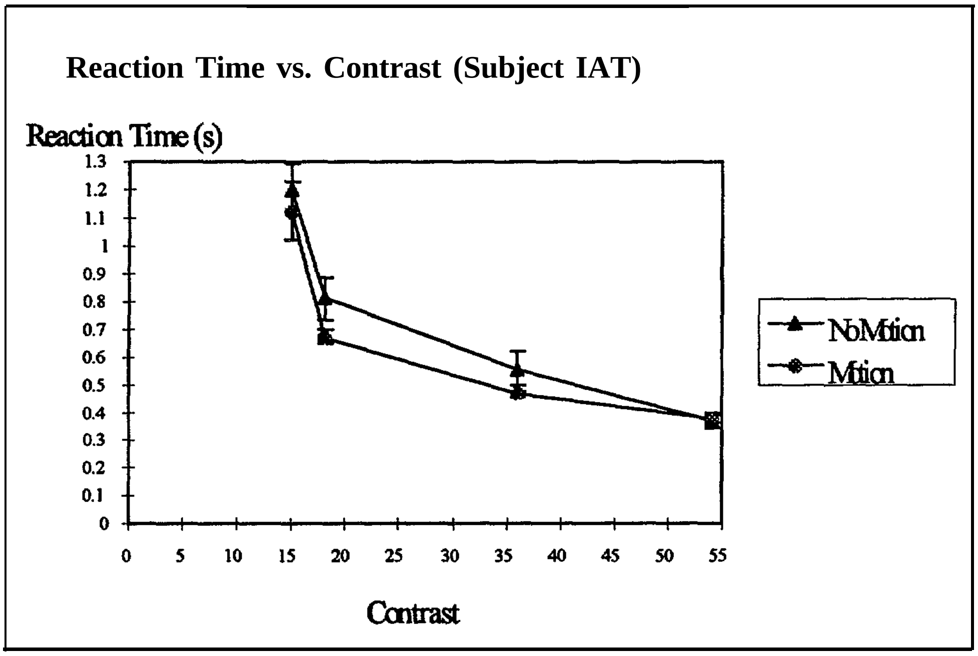

FIGURE 3. Time to react as a function of contrast with and without motion.

3. Detection of 1 of 4 equally likely possible signals

The conditions for this experiment were as follows:

Experiment 3. Detecting one of four equally likely identical targets viewed peripherally				
Task	Fixation	Lighting	Viewing	Target Shape
Detection with uncertainty	4.2 deg.	Day	Head down	9.2 Arcmin Gaussian

Figure 4 displays histograms for two subjects from the situation where one of four targets is possible and the subject's task is merely to say whether one, any one, has occurred. We see the same pattern in these histograms as was seen for the simple detection of one target. Table III summarizes these results, it differs from Table II in that there are columns for each of the four possible stimulus locations and a column for average performance. Again, average times to react favor the MEWS targets by 122 msec for BLG, 268 msec for DDN and 3 19 msec for IAT.

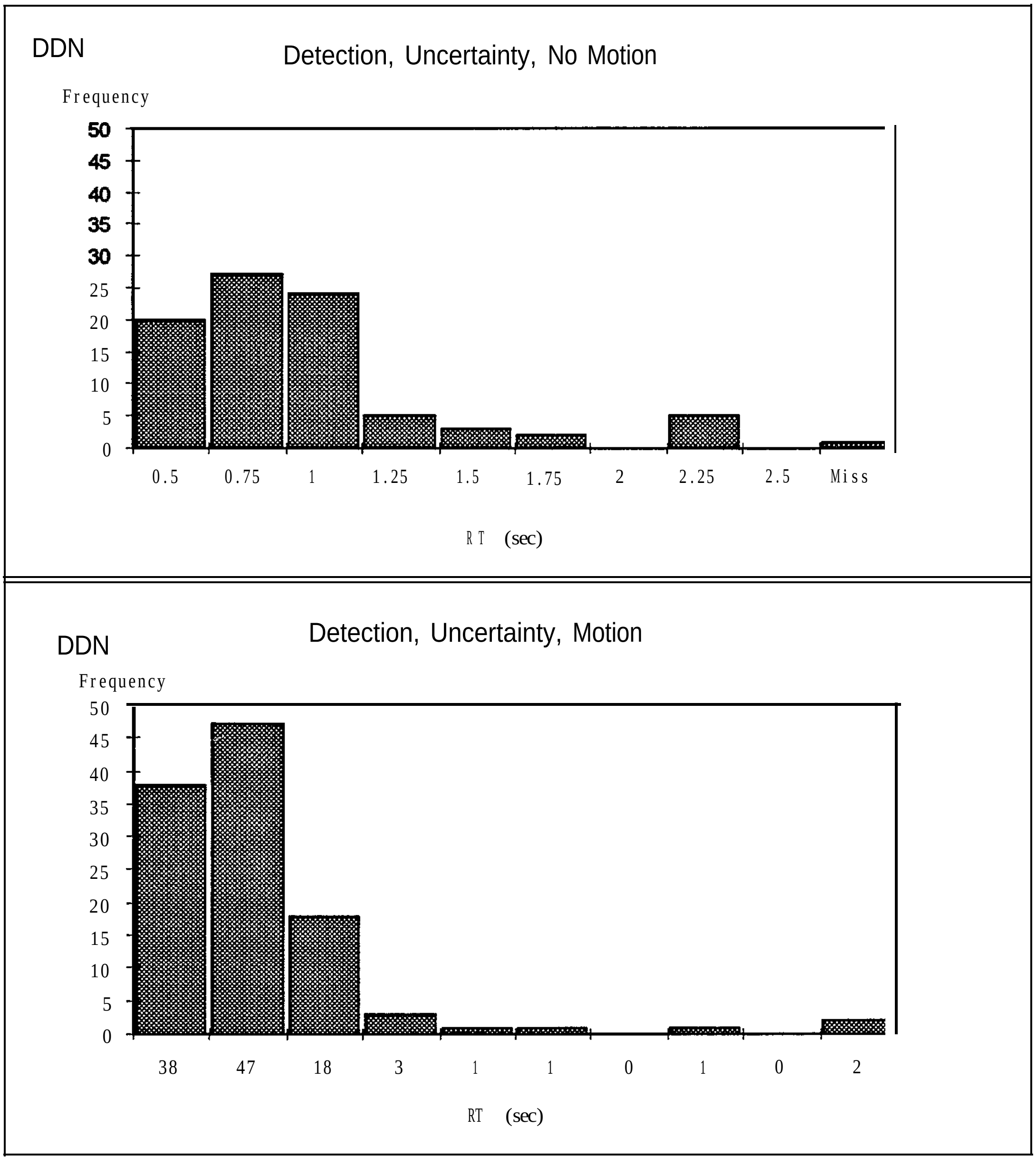

Figure 4. Frequency distributions of time-to-react for spatially uncertain targets with (below) and without (above) motion.

4. Identification of 1 of 4 equally-likely possible signals

Conditions for this experiment were:

Experiment 1A. Detecting a single target viewed peripherally

Task	Fixation	Lighting	Viewing	Target Shape
Simple Detection	4.2 **deg.**	**Day**	Head down	9.2 Arcmin Gaussian

In this experiment, observers are given a double judgment response. A first button push is used to indicate that a decision as to target presence has **been** reached. The second button push, which is not timed, is used to indicate which of the four signals was seen. Figure 5 shows histograms of the data for two subjects. MEWS targets are seen more accurately and more rapidly. Table IV summarizes results for three subjects. MEWS targets are seen more quickly by an average of 219 msec for BLG, 286 msec for DDN and 327 msec for IAT. Non-MEWS targets are not seen to a much larger extent than MEWS targets. Such events are critical because they indicate a failure of the non-MEWS signal to communicate its message. For example, consider the data in Table IV for DDN. He missed 25 of 244 target presentations. The time to react for those 25 was > 2.4 sec but was not recorded. Taking these values as 2.4 sec, itself a conservative estimate, would have raised the average by over 100 msec . The same adjustment for MEWS targets would have led to a negligible change since DDN only missed 2 of 217 MEWS presentations. The net result is that the advantage for MEWS targets would have been estimated as over 380 msec , itself a conservative estimate.

Summary of Results of Proof of Concept Experiments

These experiments have pitted non-MEWS and MEWS targets directly against one another. We randomly interleaved non-MEWS and MEWS target presentations with the result that the observer never knew which of the two types would be next, and all uncontrolled factors which could cause variations in the observer's sensory capability, must therefore have affected MEWS and non-MEWS stimuli equally on average.

The reader will recall that we adjust target contrast to threshold or to a multiple thereof for each subject. This is accomplished in a preliminary experiment of some several dozen trials in which an adaptive procedure is undertaken to find a stimulus for which about 75% of the response are correct. That process has its own variability. Nonetheless, when we measure performance as quantified by detectability (d') in our tasks, we effectively see how close we came to finding threshold. At threshold d' should be about 1.0. If it is measured to be more we were a bit too high in contrast, if less, too low. Taking d' as a proxy for stimulus strength allows us to reexamine the issue of time to react as a function of contrast (using detectability as a proxy for contrast). Figure 6 shows the covariation of time to react and d' for all three subjects in the proof of concept tests and for all three tasks. Performance on a given task for a given subject is represented by the end of the directed arrow. The arrowhead indicates the reaction time for the MEWS signal, Solid lines are for simple detection, dashed for one of four detection and dotted for identification. There is one clear trend and another that we think is likely to emerge with further testing. The most obvious is that at a given contrast MEWS targets are always seen more rapidly (arrows point down), on average, than non-MEWS targets. The next is that detectability is almost always higher for MEWS targets than for non-MEWS targets at the same contrast.

The variability that we observe among subjects is no more than that typically observed with threshold experiments. Variability generally declines with the (square root of the) number of trials used, as would be expected. Interobserver difference in average reaction times are not very large. For example, in Experiment 1, subjects BLG, DDN and IAT show values of 1.3, 1.1, and 1.2 respectively with relative contrasts of 33, 35 and 30 respectively for non-MEWS targets and 1.0, 0.7 and 1.0 for MEWS targets. Numbers of trials were 100, 125 and 35 respectively. When we compare MEWS performance with non-MEWS performance by taking the difference of average reaction times, the result is a value with more variance across subjects, because of statistical necessity.

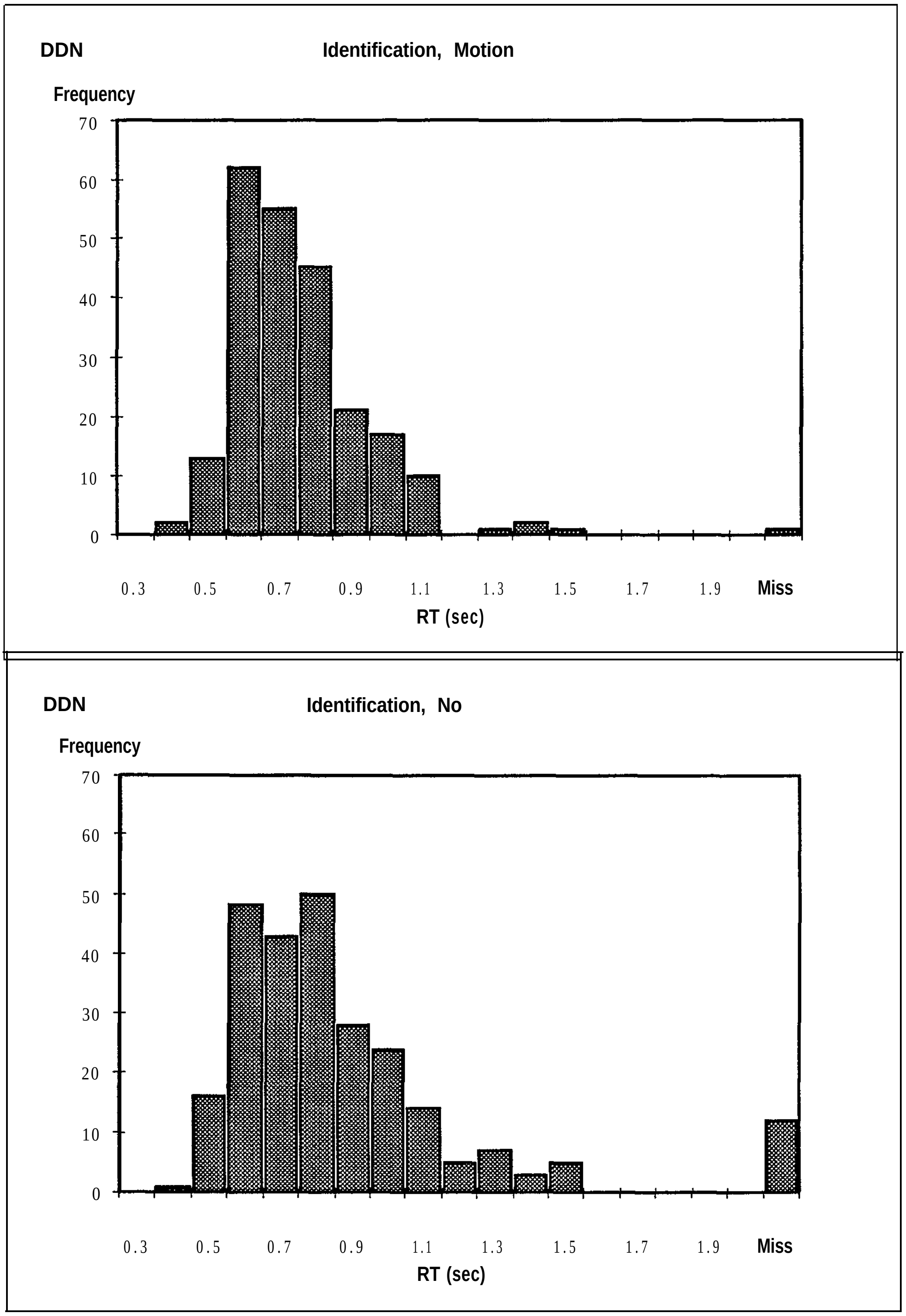

FIGURE 5a. Frequency distributions of time to react for identification with (above) and without (below) motion.

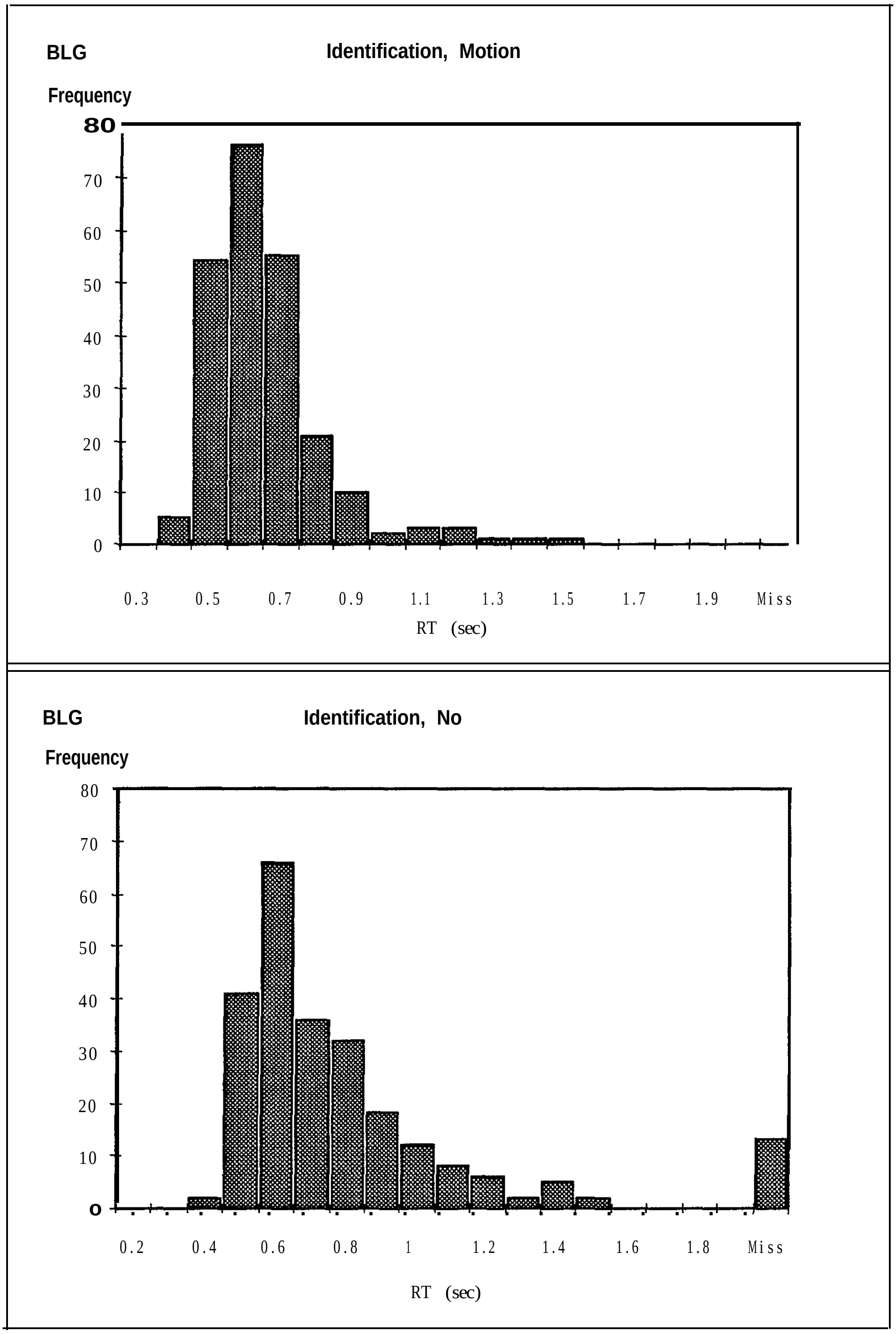

FIGURE 5b. Frequency distributions of time to react for identification with (above) and without (below) motion.

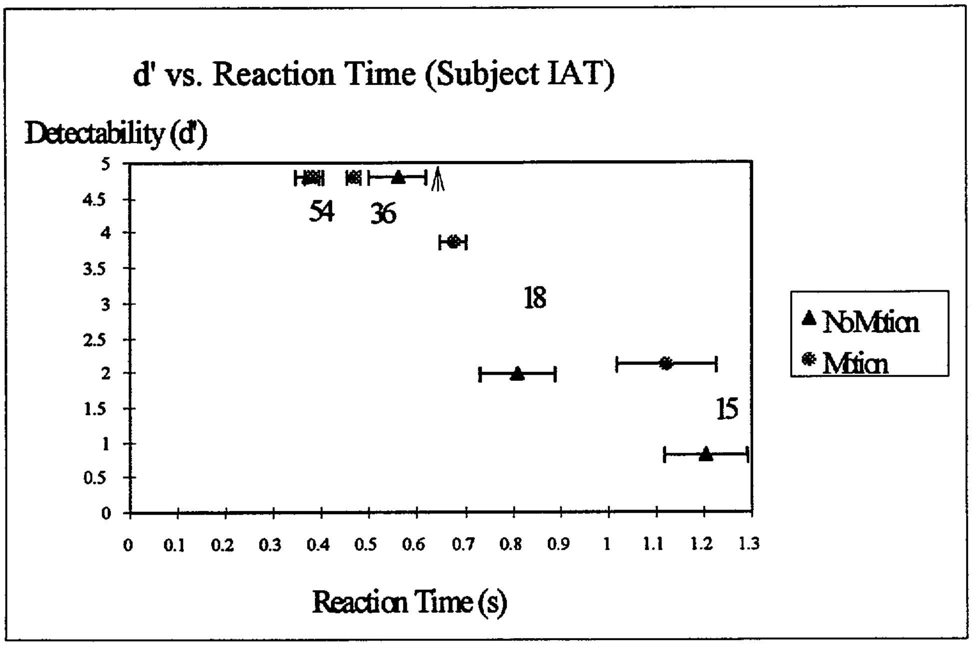

FIGURE 6. Detectability versus time to react.

5. Detection of one signal, each of six signals studied

The conditions for this experiment were as follows:

Experiment 5. Detecting a single target viewed peripherally				
Task	Fixation	Lighting	Viewing	Target Shape
Simple Detection	4.2 deg.	Day and night	Head down	Iconic

This experiment was the first of those aimed at benchmarking performance of MEWS warning signals. No comparison signals were tested since the first four experiments had served to establish the utility of MEWS principles.

The six signals were, respectively: a) railroad crossing occupied ahead (b) encroaching vehicle in intersection ahead (c) stopped vehicle in road ahead (d) emergency vehicle ahead, (e) too fast for curve ahead, and (f) too fast for stop sign ahead. Data for the simple detection of each of these individually are shown in Table V. The first half of this table contains performance measures for three subjects tested under daytime viewing conditions (room lights fully on, luminance measured on nearby surface 27.9 CD/M^2). The second half contains data for nighttime viewing conditions (room lights fully off, shade closed, luminance on nearby surface roughly 0.091 CD/M^2).

The first item to note is that there is little systematic difference in either average time to react in comparing one of these signals to another or in comparing them to the content-free MEWS signal used in the first four experiments. In other words, this points to consistency of performance with MEWS signals, irrespective of their informational content, shape, etc. The next thing to note in the data, is that night viewing conditions (as opposed to day) lead to a slight, about 100 msec , increase in time to react. This is a well-known phenomenon

6. Detection of one of six possible signals

The conditions for this experiment were as follows:

Experiment 6. Detecting a single target viewed peripherally				
Task	Fixation	Lighting	Viewing	Target Shape
Simple Detection	4.2 deg.	Day	Head down	9.2 Arcmin Gaussian

In this experiment we employ the same six signals, but these can be summoned at random and the observer has no prior knowledge of which will be presented. Signals are presented at their respective threshold contrasts as determined in separate tests preliminary to Experiment 5. Performance under daytime viewing conditions is shown in Table VI (first half). It may be seen that this uncertainty raises time to react to a small degree (this must be due a cognitive cause because the motor response is the same as in the prior experiment). It also lowers, for most signals, the detectability. Both of these phenomena are known in the human factors literature. It is likely that an increased number of possible signals will further erode performance, even though the observer's task is merely to say whether (and when) a signal has been presented. Under nighttime viewing conditions, the same two trends may be seen: time to react, on average, goes up and detectability goes down. These data are shown in the second half of Table VI.

7. Identification of one of six possible signals

The conditions for this test were as follows:

Experiment 7. Identifying one of six targets viewed peripherally				
Task	Fixation	Lighting	Viewing	Target Shape
Identification	4.2 deg.	Day/Night	Head down	Iconic

This test is the crucial benchmark of the study for it determines the upper limit on identification performance achievable with signals of this sort. It was designed to determine whether the human visual nervous system is capable of correctly identifying which of a number of possible warning signals had been presented. First, we consider the data obtained under the experimental conditions (at threshold). Then we take up an extrapolation of these data to suprathreshold levels.

At threshold, despite the more complex cognitive response required in the identification task, there appears to be little degradation of time to react averaged across signals for the three observers. These data are summarized in Table VII. Observer DSG exhibits roughly a 100 msec time to react increase, RAK shows virtually no change, and RWK shows about a 100 msec decrease, each value comparing performance to the one of six detection performance. These values fall within the error of these measurements. Similar findings were gained for nighttime viewing as shown in the table.

The next step in extrapolating these results to actual operating conditions would be to ask: How much could identification performance improve if contrast were increased. In this apparatus the use of contrast cannot exceed a ceiling set by the superimposed environment owing to head-up signaling. Contrasts used were on the order of 5% at threshold; a twenty-fold increase was thus available for use. Detectabilities in the range that we have measured, roughly 1.0 at the minimum to 4.0 at the maximum, would thus be able to increase in proportion to the contrast. Hence detectabilities could have gone as high as 20 to 80. Consider the smaller of these two numbers. A detectability of 20 implies sampling distributions of the decision variables separated by about 20 standard deviation units. This leads to an approximate calculation of the expected error rates (misidentifications). Those rates would be expected to be, at the most, about 1 in a number very much larger than one trillion, even taking account of the contrast ceiling imposed by head-up viewing. There is little reason to think that any real display would have significantly inferior numbers. Thus, we conclude that, from the perspective of visual limitations, there is no reason to think that misidentifications need occur for real displays, and that answer is independent of the nature of the signals used, provided that they are signiftcantly suprathreshold. The assumptions underlying the foregoing computation, and on which this conclusion rests, are simple: we are assuming a standard signal detection theory model in which sensory events are represented in a decision space within which distances between candidate hypotheses are given by detectabilities and that Gaussian distributions pertain. The conclusion, however, relates solely to sensory capability. It should not be used to infer that human observers will not make blunders of identification (e.g. knowing the right answer - pushing the wrong button).

8. Detection of one signal with sensory loading

The conditions for this test were as follows:

Experiment 8. Detecting one target with a simultaneous steering task				
Task	Fixation	Lighting	Viewing	Target Shape
Steering/detection	**4.2** deg.	Day/Night	Head up	**9.2** Arcmin Gaussian

This task pits warning signal against other visual input to which the observer is obliged to attend and compares the efficacy of MEWS and non-MEWS targets. Sensory loading is accomplished in a manner designed to contain ingredients similar to those in a vehicle guidance situation. A television monitor is placed in front of the observer with the warning signal monitor seen reflected on a half-silvered mirror between the observer and the monitor. The first monitor is controlled to present a guidance game that the observer uses a joystick to play. An annulus is seen on it and an easily visible target moves about with Brownian unpredictability, except when the joystick is activated. Then, the joystick will move the target in a direction corresponding to a sum of its deflection (left moves it left, forward moves it up, etc.) and the random motion signal The observer's task is to keep the target within the annulus. At the same time, a detection task, similar to the one used in Experiment 1, is run. Table VIII shows data summaries from this experiment. MEWS signals are seen more quickly, an average of 231 msec for EPH, of 194 msec for DSG, and of 327 msec for SW. DDN showed a 155 msec advantage for MEWS signals but he missed 2/3 of the non-MEWS signals presented to him, thus illustrating the conservatively biased nature of the endpoint that we report. Inclusion of those missed signals would have raised his mean reaction time advantage for MEWS signals by over 600 msec . Thus, our MEWS signals have proven to be more detectable and more quickly seen in a sensory loading situation.

9. Detection of one of four signals with sensory loading

The conditions for this test were as follows:

Exueriment 9. Detecting one of four targets with a simultaneous steering task				
Task	Fixation	Lighting	Viewing	Target Shape
Steering/detection	**4.2** deg.	Day	Head up	**9.2** Arcmin Gaussian

This experiment extends Experiment 8 to the situation where the observer must detect the presence of one of four equally likely possible signals. Again non-MEWS and MEWS signals are r andomized throughout the task and the task is superimposed upon a guidance task. Table IX summarizes the data from this experiment. MEWS signals were seen an average of 43 1 msec more quickly for EPH, 99 msec more quickly for DSG, 287 msec for DDN and 301 msec for SYY in the case of ramped stimuli. Misses were numerous for non-MEWS signals for each of these observers but not for MEWS signals; the detectability advantage for MEWS signals was over a factor of 2.0 for each observer. Hence, it is apparent that MEWS signals are especially salient.

10. Effect of distractors on simple detection

The conditions for this test were as follows:

Experiment 10. Detecting a target seen amidst distractors				
Task	Fixation	Lighting	Viewing	Target Shape
Detection	**4.2** deg.	Day/Night	Head up	**9.2** Arcmin Gaussian

This study probed the comparison between non-MEWS and MEWS signals in a situation where head-up viewing of a simulated driving scene supplied extraneous movement stimuli similar to those that would be encountered in vehicle operation. The distracting scene was presented on a TV monitor placed before the observer. The simulation was of a drive along a relatively changeless rural highway. Roadside signs, overtaking vehicles, and vehicles overtaken occasionally entered the scene. This simulation was developed with a special purpose modeling software and rendered for us at the Environmental Simulation Laboratory at UC Berkeley. Warning signals were presented in the midst of this series of distracting stimuli. They were presented superimposed upon the hood of the simulated vehicle, a location adjacent to the one containing the highest velocity flow field in the visual scene.

Table X presents the data from five subjects taken at threshold contrast. There is a mean reaction time advantage for MEWS signals over non-MEWS signals of 163 msec for EPH, 102 msec for DDN, and 155 msec for DSG. SYY shows a 51 msec advantage for the non-MEWS target. In sum, these differences in reaction time are not as large as those found in other phases of our study.

While there is a tendency across all subjects for greater detectability of the MEWS signal, this is not true for all. This negative finding is understandable and especially instructive. When one creates a motion signal one has the choice of a direction for the motion. In the present case the motion in our single MEWS signal was orthogonal to the motion in the immediately adjacent distracting flow field. Apparently, this fact lowers its salience considerably. It is therefore urged that designers consider the background against which their targets will be seen. We have made no systematic study of this issue and suggest that it may be an appropriate area for further study.

11. Effect of distractors on one of four detection

The conditions for this test were as follows:

Experiment 11. Detecting one of four targets amidst distractors				
Task	Fixation	Lighting	Viewing	Target Shape
Detection	4.2 deg.	Day	Head up	9.2 Arcmin Gaussian

This study, like Experiment 10, sought information about the MEWS advantage, if any, in the presence of distractors, when several different warning signals (each with a different direction of motion) were possible. Table Xl presents the data. Here we see a different picture than for the detection of one signal Apparently, when any one of several signals can appear, there is a distinct and quantifiable MEWS advantage. but different also from that for the nondistractor experiments. A clear average reaction time advantage was found for EPH (369 msec), DSG (342 msec), SYY (172 msec) and DDN (167 msec).

DISCUSSION

While the results of our study point at the conclusion that MEWS signals are superior in several ways, the reader is cautioned that the evidence used to reach this conclusion is finite and rests upon a number of factors and assumptions that the designer must be aware of. These are detailed here.

1) Signals equally likely: In the real world setting, some warning signals may be more likely than others and the rational observer will devote more attention to those, lowering reaction times and improving identification performance for the more frequently occurring signals.

2) Cost of Errors: In the laboratory, errors are costly only insofar as the observer wishes to perform well in the tasks placed before him/her. In the real world setting errors can have considerable cost. Certain errors can be more costly than others. A false alarm related to lane edge incursion is far less costly that a miss for imminent collision for example. Confusing a lane edge incursion with an imminent collision is less costly than the opposite. The laboratory tests, nonetheless, assume equal cost for each type of error.

3) Responses artificial: in the real world setting the response to a warning signal may be a several step process involving slow motor activity (e.g. verification of event being signaled, calculation of best response, then brake pedal or steering wheel activation). Our benchmarks, on the other hand depict solely the performance achievable with a well-learned simple and rapid motor response – the button push. Hence the designer can expect to find actual values for time to react inferior to those. displayed here.

4) Asynchrony: in the real world setting, certain warnings will arrive without forewarning from the events that the driver can see. Other signals will be forewarned by those events (e.g. gradual incursion toward the lane edge is visible to a driver paying attention and the warning signal will be triggered when a criterion has been satisfied. Our benchmarks are derived from an artificial situation in which, (for identification tests) the time of occurrence is known exactly to the observer. This allows us to benchmark the best obtainable accuracy of response. In the reaction time study signals occur anywhere in a 5 second interval, not the nearly infinite interval in which real life signals can occur.

5) Practice: The laboratory experiments are conducted only after observers have had a chance to practice their observations and the associated responses. In the real world, learning curve issues are influential.

6) Contrast control: In the laboratory, we expend very large effort to precisely specify the contrast with which signals are seen. In the real world the contrast depends upon a host of unknown and uncontrollable factors related to illumination sources and to reflectivity of objects viewed by the observer. More subtly, we adjust contrast in the laboratory to be a fixed multiple of the threshold contrast for a given warning signal. For example, time to react studies are run with signals adjusted to be between one times and twice their usual threshold contrast. This convention standardizes the benchmark. By doing so we are then able to extrapolate performance to higher values of contrast for which actual error rates would be very small and thus much harder to measure.

7) Finite duration: In the laboratory, a warning signal will be extinguished, in some tests such as threshold contrast determining tests not reported above, as quickly as 200msec. In real life the signal would not be extinguished until the observer reacted to it.

8) Location in the visual field: In the laboratory, visual signals were always presented at a pre-designated location in the visual field. In the real world, one would not expect the warning signal system to be able to compensate for the unpredictable angle of gaze adopted by the driver.

9) Number of possible warning signals: Our laboratory tests have used six warning signals. Real world practice may lead to as many as twelve signals (or more) and all performance values would be expected to deteriorate with increased numbers of signals.

10) Suboptimal graphic content of warning signals tested: The warning signals used in this project reflect several features that may be viewed as approaching optimal (or desirable) and several that do not. Use of a cue to accommodation, use of a coordinate system within which signals can be displayed, the choice to not allow signals to overlap in space nor to have similar shape, the compactness of the overall display, and especially incorporation of MEWS signaling are all features worthy of emulation, but which might be improved with fine tuning. The precise form of the graphic features of the warning signals we employed is neither represented as desirable nor is it thought to be optimal. It would be expected that professional graphic design which this project did not employ, would improve the look and the efficacy of all of the warning signals that we have used.

CONCLUSIONS

We have demonstrated that an innovative means of delivering warning signals by incorporating motion in them, lends quicker reaction time, higher detectability, better salience and better immunity to distraction. These MEWS signals are likely to prove to be more immune to the effects of blur, fog and so on as well. We have developed an icon-centered warning signal display that accommodates as many as eighteen different warning signals placed in logical relation to the vehicle. The vehicle icon serves two indispensable purposes, especially for heads-up viewing: it provides a stimulus for accommodation and it embodies a coordinate system within which to interpret the warnings and to quickly see the appropriate required response. Guidelines for warning signal designers have been developed within the project.

We have developed a testing system that can be used by warning signal designers to fashion signals of arbitrary complexity, for use in either head-up or head-down displays, and to test their properties. That system is constructed of readily available components and requires only unsophisticated software.

Use of the benchmarks: the main use of the benchmarks presented in data Tables cited above is for comparison with those obtained from other warning signals systems developed by designers. If a new design can produce its own benchmark values better than or within the error range of the values presented here, then the designer can be confident that the new design is acceptable as it stands. Benchmark values inferior to those presented here should alert the designer that better results could be achieved with design alteration.

Finally, we have been able to answer the fundamental question related to plans for a multiplicity of warning signals: our evidence suggests that there is no visual limitation that would prevent a vehicle operator with normal vision from correctly identifying a warning signal which is one of many (e.g. up to 12) possible; such identification can be virtually error-free at contrast levels achievable in vehicles.

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GLOSSARY

ATIS: Advanced Traveler Information Systems

Arcmin: One minute of arc, a measure of visual angle. 60 minutes make one degree The entire visual field of a normal individual is about 180deg. wide but less in the vertical direction.

deg: An angle of one degree of arc (see Arcmin).

Detection: The sensory act of correctly discerning the presence of as signal. Detection is quantified by two statistical measures, the ***false alarm rate*** (incorrectly "seeing" a signal when none was present, and the ***miss rate*** (incorrectly failing to see the signal. These two rates may be used to infer a detectability measure for the signal.

Distractor: A sensory stimulus that distracts an observer from attending to the signal to be detected or identified.

Fovea: The highly acute central 2deg. diameter area of the visual field. When a normal observer directs his/her attention at an object in the visual field, most often the image of that object is brought into the fovea by means of eye movements. One's acuity declines dramatically outside of the fovea so that reading, and other visual signal identification, requires stimuli to be in the fovea. Extrafoveal vision, however, is attuned to the task of perceiving self-motion, a key element of vehicle guidance.

HUD: (Head-up display): An instrumentation/information display modality intended for the vehicle operator which, by reflection off of the windscreen, allows the operator to gain the information while looking with his/her head up. A head down display is the conventional in-the-dashboard configuration.

ITS: Intelligent Transportation Systems (formerly Intelligent Vehicle Highway System -IVHS)

IVES: (see ITS)

Identification: The sensory act of correctly selecting which of a plurality of possible signals has been detected. The ***confusion matrix*** is the table of events which shows which signal leads to which responses, wrong or right.

M system: The magnocellular projection of the visual nervous system. Specialized to high speed and high sensitivity plus poor acuity and no color.

MEWS: Motion enhanced warning signal. This is a signal which includes motion. A non-MEWS signal is one that has no motion.

P system: The parvocellular projection of the visual nervous system. Specialized to low speed, high acuity and good color.

RT or Reaction Time: The time from presentation of a warning signal until the observer physically registers a reaction. If the reaction is a vehicle control action such as steering, or braking, then the RT measures the delay inherent in the human detection, identification and response system. The simple reaction time is measured in a task involving only one warning signal, known exactly to the observer. If the task involves identifying one of M warning signals, the time to react is termed the ***choice reaction time.***

Salience: The ability of a signal to maintain identifiability in the presence of distractors.

Signal Uncertainty: A quality of a sensory detection task in which the signal to be detected is specified statistically (i.e. detect a signal when it is one of M possible signals). ***If*** M=l, ***the*** task is termed ***simple detection. In the*** detection of warning signals, this is the **realistic** situation, as the vehicle operator is presumed not to have foreknowledge of what will be warned of.

Task: A task is a sensory-based activity with objective endpoints and one or more measures of achievement. In our experiments ***we*** ask observers to undertake a ***primary task*** of vehicle guidance, all the while being alert to the need to react correctly to one of a plurality of warning signals in a ***secondary task.*** The latter task is termed ***loaded*** because of the need on the part of the observer to continually attend to the primary task.

Threshold Contrast Energy: ***This*** term is a derivative of ***threshold contrast, the*** minimum stimulus intensity difference from a background intensity, divided by the background, required for the stimulus to be seen at a specified level of statistical accuracy. Threshold contrast energy generalizes the term to a visual stimulus of arbitrary spatial and temporal extent as the integral of the squared contrast over space and time.

APPENDIX:

TABLES REFFERED TO IN THE TEXT

TABLE I Proof of Concept Tests: Detection of one spot				
Subject		No Motion		Motion
BLG	Avg RT	1.27		0.99
	StDev RT	0.55		0.38
	# Hit Trials	82		85
	# Miss Trials	21		5
	Rel. Contrast	33		33
	d'	1.56		2.33
	FA Rate	0.23		
DDN	Avg RT	1.1		0.72
	StDev RT	0.41		0.15
	# Hit Trials	122		124
	# Miss Trials	7		0
	Rel. Contrast	35		35
	d'	3.59		5.23
	FA Rate	0.02		
IAT	Avg RT	1.18		1.01
	StDev RT	0.54		0.42
	# Hit Trials	23		35
	# Miss Trials	13		0
	Rel. Contrast	30		30
	d'	1.23		4.12
	FA Rate	0.19		

TABLE II: Time to React Versus Relative Contrast -- Subject IAT						
mean RT	1.2	1.12		mean RT	0.56	0.47
st. dev	0.5	0.55		st. dev	0.37	0.09
# hits	33	28		# hits	39	42
# misses	15	1		# misses	0	0
contrast	15	15		contrast	36	36
# FA	6			# FA	0	
FA Rate	0.38			FA Rate	0	
# blanks	16			# blanks	17	
mean RT	0.81	0.68		mean RT	0.43	0.38
st. dev	0.44	0.19		st. dev	0.19	0.08
# hits	32	46		# hits	45	37
# misses	3	0		# misses	0	0
contrast	18	18		contrast	54	54
# FA	4			# FA	1	
FA Rate	0.27			FA Rate	0.06	
# blanks	15			# blanks	17	

TABLE III Proof of Concept: Detection of 1 of Four

			Stationary					Motion				
Subject			Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Stim 8	Avg
		RT Mean	1.09	1.25	1.48	1.16	1.25	0.89	1.37	1.24	1.01	1.13
BLG		RT StDev	0.44	0.57	0.62	0.57		0.34	0.63	0.49	0.41	
		# Hits	63	29	32	36	160	59	43	40	62	204
		# Miss Trials	7	22	27	24	80	0	18	27	1	46
		# Miss ID	0	0	0	0		0	0	0	0	
		# FA Trials	40		FA Rate	0.43		# Blanks	94			
		d'	1.37	0.32	0.23	0.4	0.62	3.42	0.59	0.34	2.23	1.09
DDN		RT Mean	1.05	1.39	1.31	1.1	1.21	0.84	1.1	0.98	0.86	0.95
		RT StDev	0.39	0.55	0.49	0.42		0.24	0.38	0.36	0.24	
		# Hits	80	62	67	63	272	70	70	78	63	281
		# Miss Trials	1	15	19	5	40	0	2	0	0	2
		# Miss ID	0	0	0	0		0	0	0	0	
		# FA Trials	9		# Blanks	143		FA Rate	0.06			
		d'	3.75	2.39	2.3	2.98	2.67	4.77	3.44	4.77	4.77	3.93
IAT		RT Mean	1.2	1.5	1.34	1.29	1.37	0.94	1.08	1.13	0.95	1.06
		RT StDev	0.47	0.57	0.48	0.53		0.36	0.34	0.48	0.31	
		# Hits	42	21	19	31	33	35	36	28	20	119
		# Miss Trials	2	20	8	14	3	1	7	3	1	12
		# Miss ID	0	0	0	0	0	0	0	0	0	
		# FA Trials	38		# Blank Trials	91		FA Rate	0.42			
		d'	1.89	0.24	0.74	0.7	1.59	1.59	2.11	1.19	1.51	1.54

TABLE IV: Proof of Concept, 1 of four Identification						Peripheral fixation, ramped onset					
			Stationary					Motion			
Subject			Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	stim7	Stim 8	Avg
		RT Mean	1.06	1.47	1.29	1.36	1.29	0.86	1.26	1.25	0.93	1.08
BLG		RT StDev	0.42	0.61	0.64	0.53		0.32	0.53	0.45	0.38	
		#Hits	31	23	14	17	85	34	45	36	41	156
		#MissTrials	3	15	28	14	60	2	9	14	3	28
		#MissID	4	7	6	2		2	1	9	1	
		#FATrials	32		FA Rate	0.38		#Blanks	84			
		d’	1.2	0.33	-0.25	0.34	0.52	1.55	1.21	0.58	1.65	1.33
DDN		RT Mean	1.13	1.44	1.37	1.4	1.34	0.93	1.23	1.11	0.93	1.05
		RT StDev	0.38	0.51	0.43	0.51		0.23	0.45	0.31	0.33	
		#HitS	59	64	46	50	219	61	47	61	46	215
		#MissTrials	3	8	12	2	25	0	2	0	0	2
		#MisslD	3	2	1	2		2	1	1	0	
		# FA Trials	3		FA Rate	0.03		# Blanks	119			
		d’	3.28	3.06	2.73	3.4	3.22	3.8	3.51	4.08	5.2	4.27
												Avg
IAT		RT Mean	1.44	1.45	1.34	1.55	1.45	1.11	1.24	1.08	1.04	1.12
		RT StDev	0.5	0.59	0.51	0.49		0.41	0.4	0.39	0.39	
		#Hits	20	21	15	23	33	21	28	22	21	92
		#MissTrials	3	12	11	9	3	0	3	5	1	9
		#MissID	3	2	0	0	0	1	1	1	1	
		# FA Trials	12		FA Rate	0.2		#Blanks	59			
		d’	1.57	1.08	1.02	1.41	2.21	2.52	1.98	1.62	2.19	2.18

TABLE V: Detection of Individual Warning Signals.							
Night Condition:		SIGNAL					
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Contrast	0.07	0.05	0.04	0.08	0.04	0.04
(1.0 x)	Avg RT	1.16	0.95	1.08	1.15	1.13	0.95
	Std Dev	0.43	0.31	0.4	0.42	0.41	0.37
	Hits	29	36	32	35	30	28
	Misses	13	1	8	5	13	11
	Incorrect ID	0	0	0	0	0	0
		0	4	1	1	2	2
		13					
	FA rate	0.27					
	d'	1.12	2.54	1.47	1.78	1.15	1.2
RAK	Contrast	0.05	0.05	0.04	0.04	0.05	0.04
(1.0 x)	Avg RT	1.14	1	1	1.01	1.03	0.94
	Std Dev	0.41	0.39	0.35	0.38	0.44	0.31
	Hits	34	35	32	24	31	35
	Misses	5	6	6	15	10	1
	Incorrect ID	0	0	0	0	0	0
		3	3	2	3	1	4
		14					
	FA rate	0.28					
	d'	1.72	1.64	1.59	0.88	1.28	2.49
RWK	Contrast	0.04	0.05	0.04	0.07	0.06	0.04
(1.0 x)	Avg RT	1.19	1.02	1.06	0.99	0.99	1.01
	Std Dev	0.45	0.42	0.42	0.36	0.45	0.5
	Hits	21	24	25	29	27	16
	Misses	8	10	8	10	14	18
	Incorrect ID	0	0	0	0	0	0
		5	9	8	3	2	6
		18					
	FA rate	0.32					
	d'	1.08	1.02	1.18	1.13	0.89	0.41

TABLE V: Detection of Individual Warning Signals.							
Day Condition:		SIGNAL					
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Stim. Contrast	0.03	0.03	0.02	0.03	0.03	0.03
(1.0 x)	Avg RT	0.91	0.92	0.89	1.18	0.86	1.06
	Std Dev	0.34	0.37	0.3	0.46	0.35	0.38
	Hits	41	36	40	36	32	31
	Misses	1	2	3	2	2	12
	Incorrect ID	0	0	0	0	0	0
		1	1	1	2	1	0
		16					
	FA rate	0.29					
	d'	2.53	2.18	2.04	2.18	2.13	1.15
RAK	Stim. Contrast	0.03	0.02	0.02	0.03	0.02	0.03
(1.0 x)	Avg RT	1.01	0.93	0.82	0.86	1.01	0.91
	Std Dev	0.31	0.37	0.29	0.34	0.35	0.37
	Hits	34	33	39	37	37	37
	Misses	4	4	0	4	2	4
	Incorrect ID	0	0	0	0	0	0
		0	4	4	2	5	5
		17					
	FA rate	0.38					
	d'	1.56	1.55	3.56	1.61	1.94	1.61
RWK	Stim. Contrast	0.02	0.05	0.02	0.03	0.04	0.04
(1.0 x)	Avg RT	0.93	0.58	1.13	0.92	0.57	0.64
	Std Dev	0.35	0.12	0.35	0.36	0.13	0.19
	Hits	93	43	33	39	40	38
	Misses	22	0	9	3	1	0
	Incorrect ID	0	0	0	0	0	0
		5	0	3	1	1	0
		9					
	FA rate	0.13					
	d'	2	4.37	1.92	2.59	3.08	4.37

TABLE VI: Detection of All 6 Warning Signals.							
Day Condition:		Signal					
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Contrast	0.03	0.03	0.02	0.03	0.03	0.03
(1.0 x)	Avg RT	1.01	1.04	0.97	1.2	0.78	0.96
	Std Dev	0.34	0.4	0.3	0.3	0.25	0.31
	Hits	44	33	34	21	40	27
	Misses	3	7	1	20	0	9
	Incorrect ID	0	0	0	0	0	0
		1	2	0	3	1	0
		8					
	FA rate	0.15					
	d'	2.57	1.98	2.94	1.08	4.29	1.72
RAK	Contrast	0.03	0.02	0.02	0.03	0.02	0.03
(1.0 x)	Avg RT	0.93	1.23	0.88	1.14	1.04	1.17
	Std Dev	0.25	0.43	0.33	0.36	0.37	0.39
	Hits	32	21	33	23	30	29
	Misses	1	14	2	20	4	10
	Incorrect ID	0	0	0	0	0	0
		4	5	3	2	4	5
		34					
	FA rate	0.59					
	d'	1.65	0.04	1.36	-0.13	0.97	0.44
RWK	Contrast	0.02	0.05	0.02	0.03	0.04	0.04
(1.0 x)	Avg RT	1.46	1.09	0.64	0.84	0.9	0.97
	Std Dev	0.41	0.43	0.44	0.48	0.42	0.31
	Hits	6	22	2	5	39	28
	Misses	25	14	40	30	22	15
	Incorrect ID	0	0	0	0	0	0
		0	2	1	1	1	4
		3					
	FA rate	0.07					
	d'	0.61	1.76	-0.19	0.41	1.83	1.87

TABLE VI: Detection of All 6 Warning Signals.							
Night Condition:		Signal					
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Contrast	0.07	0.05	0.04	0.08	0.04	0.04
(1.0 x)	Avg RT	0.92	1.16	1.19	1.02	1.18	0.88
	Std Dev	0.31	0.37	0.36	0.45	0.32	0.33
	Hits	37	23	28	38	25	42
	Misses	3	8	14	5	12	6
	Incorrect ID	0	0	0	0	0	0
		1	4	5	2	3	2
	FA trials	9					
	FA rate	0.21					
	d'	2.23	1.44	1.22	1.99	1.25	1.94
RAK	Contrast	0.05	0.05	0.04	0.04	0.05	0.04
(1.0 x)	Avg RT	1.08	1.15	1.03	1.35	0.9	0.88
	Std Dev	0.35	0.47	0.34	0.35	0.34	0.23
	Hits	42	23	41	11	6	30
	Misses	2	18	1	30	23	1
	Incorrect ID	0	0	0	0	0	0
		2	3	7	10	1	2
	FA trials	17					
	FA rate	0.36					
	d'	2.04	0.51	2.32	-0.26	-0.46	2.2
RWK	Contrast	0.04	0.05	0.04	0.07	0.06	0.04
(1.0 x)	Avg RT	1.53	0.85	1.17	1.2	1.21	1.51
	Std Dev	0.42	0.71	0.47	0.5	0.43	0.26
	Hits	5	5	17	17	11	2
	Misses	27	33	26	21	30	38
	Incorrect ID	0	0	0	0	0	0
		4	2	2	4	3	2
	FA trials	15					
	FA rate	0.29					
	d'	-0.47	-0.58	0.28	0.41	-0.08	-1.1

TABLE VII: Identification of All 6 Warning Signals.							
Night Condition:							
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Contrast	0.07	0.05	0.04	0.08	0.04	0.04
(1.0 x)	Avg RT	1.08	1.42	1.33	0.92	1.38	1.05
	Std Dev	0.28	0.36	0.26	0.24	0.29	0.36
	Hits	29	12	26	35	29	28
	Misses	7	22	15	1	10	10
	Incorrect ID	9	1	2	1	1	3
		3	1	2	1	1	3
	FA trials	15					
	FA rate	0.32					
	d'	0.84	0.07	0.74	2.07	1.07	0.95
RAK	Contrast	0.05	0.05	0.04	0.04	0.05	0.04
(1.0 x)	Avg RT	1.18	1.18	1.07	1.23	1.37	0.95
	Std Dev	0.36	0.42	0.33	0.26	0.43	0.32
	Hits	35	36	44	10	6	40
	Misses	10	12	2	25	29	1
	Incorrect ID	1	5	1	3	5	1
		2	8	7	4	4	4
	FA trials	17					
	FA rate	0.31					
	d'	1.21	0.96	2.02	-0.14	-0.54	2.16
		65	61	54	42	44	46
RWK	Contrast	0.04	0.05	0.04	0.07	0.06	0.04
(1.0 x)	Avg RT		0.93	1.48	1.49	1.3	1.99
	Std Dev			0.18	0.33	0.3	
	Hits		1	12	15	6	1
	Misses		27	36	26	19	43
	Incorrect ID		4	2	0	4	3
			1	0	1	2	2
	FA trials						
	FA rate						
	d'						

TABLE VII: Identification of All 6 Warning Signals.							
Day Condition:							
Subject		Ambulance	Disabled car	Icy Road	L. Turn	Railroad	Stop
DSG	Contrast	0.03	0.03	0.02	0.03	0.03	0.03
(1.0 x)	Avg RT	1.08	1.16	1.21	1.39	0.94	1.09
	Std Dev	0.28	0.32	0.27	0.35	0.22	0.36
	Hits	33	36	36	22	42	27
	Misses	2	5	2	20	1	9
	Incorrect ID	8	2	1	1	0	1
	FA Trials	0	1	2	0	1	3
	Blank FA	8					
	FA rate	0.18					
	d'	1.65	1.91	2.35	0.95	2.9	1.54
RAK	Contrast	0.03	0.02	0.02	0.03	0.02	0.03
(1.0 x)	Avg RT	0.93	1.24	0.95	1.14	0.99	1.13
	Std Dev	0.26	0.36	0.28	0.36	0.29	0.38
	Hits	45	30	42	38	39	44
	Misses	0	5	2	3	4	4
	Incorrect ID	0	1	0	0	1	0
		3	1	1	0	1	0
		6					
	FA rate	0.17					
	d'	4.21	1.94	2.65	2.42	2.17	2.35
RWK	Contrast	0.02	0.05	0.02	0.03	0.04	0.04
(1.0 x)	Avg RT	1.19	0.98	1.32	1.19	0.87	0.79
	Std Dev	0.35	0.35	0.33	0.33	0.22	0.26
	Hits	31	38	20	31	33	42
	Misses	8	0	18	13	1	0
	Incorrect ID	4	0	2	0	0	0
		1	1	3	1	1	2
		6					
	FA rate	0.12					
	d'	1.76	4.42	1.18	1.71	3.06	4.42

TABLE VIII: Sensory Loading Experiment (1 of 1)								
Subject		No Motion	Motion			No Motion	Motion	
EPH (1.0x)	Avg RT	1.19	0.97	DDN (1.0x)	Avg RT	1.3	1.15	
	StDev RT	0.52	0.36		StDev RT	0.6	0.54	
	# Hit Trials	33	39		# Hit Trials	34	98	
	# Miss Trials	8	1		# Miss Trials	58	15	
	contrast	12	12		contrast	7	7	
	d'	1.83	2.92		d'	0.43	1.88	
	FA Rate	0.17			FA Rate	0.22		
DSG (1.0x)	Avg RT	1.39	1.19		Stimulus specifics:			
	StDev RT	0.51	0.42		**1) presented in one position only**			
	# Hit Trials	11	36		2) presented 7.27 deg from fixation			
	# Miss Trials	31	6		3) variable onset duration (between 0.5 and 4.0 sec) 4) maximum presentation duration of 2.5 sec			
	Contrast	11	11		**5) Stimulus ramped on**			
	d'	0.47	2.18					
	FA Rate	**0.13**						
SYY (1.0x)	Avg RT	1.28	0.96					
	StDev RT	0.43	0.3					
	# Hit Trials	29	41					
	# Miss Trials	8	8					
	Contrast	0	0					
	d'	4.51	4.7					
	FA Rate	0						

TABLE VIII Cont'd: Sensory Loading Experiment (1 of 1)							
DDN (1.5x)		No Motion	Motion		DDN (1.0x)	No Motion	Motion
	Avg RT	0.68	0.6		Avg RT	1.17	1.16
	StDev RT	0.36	0.17		StDev RT	0.61	0.59
	# Hit Trials	41	41		# Hit Trials	14	31
	# Misses	3	0		# Misses	19	12
	Contrast	0	0		Contrast	0	0
	d'	1.92	3.67		d'	1.12	1.9
	FA Rate	0.33			FA Rate	0.1	
DSG (1.5x)					SYY (1.5x)		
	Avg RT	1.3	1.1		Avg RT	0.83	0.56
	StDev RT	0.63	0.6		StDev RT	0.57	0.12
	# Hit Trials	9	19		# Hit Trials	16	23
	# Miss	7	2		# Miss	0	0
	Contrast	11	11		Contrast	9	9
	d'	1.49	2.64		d'	4.39	4.39
	FA Rate	0.09			FA Rate	0.13	
RAK (1.5x)							
	Avg RT	0.71	0.77				
	StDev RT	0.32	0.25				
	# Hit Trials	19	13				
	# Miss	0	0				
	Contrast	16	16				
	d'	4.71	4.71				
	FA Rate	0.07					

TABLE IX: Sensory Loading Experiment (1 of 4)

Subject		Stationary					Motion				
EPH (1.5x) Ramp		Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Stim 8	Avg
	RT Mean	0.923	1.680	1.31	1.15	1.27	0.66	0.93	1.01	0.73	0.83
	RT StDev	0.506	.620	0.18	0.45		0.12	0.25	0.28	0.12	
	# Hits	8	8	3	14	33	10	18	17	18	63
	# Miss Trials	0	10	6	0	16	0	2	0	0	2
	# Miss ID	0	0	0	0		0	0	0	0	
	# FA Trials	8									
	FA Rate	0.29									
	# Blank Trials	28									
	d'	3.81	0.43	0.14	3.81	1.02	3.81	1.85	3.81	3.81	2.43
DSG (1.5x) Ramp		Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Stim 8	Avg
	RT Mean	0.96	0.64	1.39	1.24	1.06	0.66	1.21	1.18	0.8	0.96
	RT StDev	0.53	na	0.81	0.33		0.14	0.34	0.41	0.18	
	# Hits	6	1	4.0E+00	8	19	9	11	17	5	42
	# Miss Trials	0	9	9	3	21	0	2	1	0	3
	# Miss ID	0	0	0	0		0	0	0	0	
	# FA Trials	3									
	FA Rate	0.21									
	# Blank Trials	14									
	d'	4.04	-0.49	0.29	1.4	0.73	4.04	1.81	2.38	4.04	2.29

TABLE IX Cont'd: Sensory Loading Experiment (1 of 4)

		Stationary					Motion				
SYY (1.5x) Ramp		Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Stim 8	Avg
	RT Mean	0.82	1.34	1.54	0.89	1.15	0.76	0.75	1.08	0.8	0.85
	RT StDev	0.24	0.65	0.55	0.22		0.12	0.12	0.34	0.15	
	# Hits	12	2	5	12	31	6	7	13	11	37
	# Miss Trials	0	6	12	0	18	0	0	0	0	0
	# Miss ID	0	0	0	0		0	0	0	0	
	# FA Trials	1									
	FA Rate	0.09									
	# Blank Trials	11									
	d'	4.58	0.66	0.79	4.58	1.67	4.58	4.58	4.58	4.58	4.58
DDN (1.5x) Ramp		Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Stim 8	Avg
	RT Mean	1.06	1.29	1.35	1.11	1.2	0.76	0.95	1.09	0.86	0.92
	RT StDev	0.5	0.58	0.6	0.52		0.17	0.4	0.37	0.36	
	# Hits	52	42	34	36	164	51	48	45	46	190
	# Miss Trials	9	25	22	15	71	0	1	2	1	4
	# Miss ID	0	0	0	0		0	0	0	0	
	# FA Trials	11									
	FA Rate	0.1									
	# Blank Trials	108									
	d'	2.32	1.6	1.54	1.81	1.79	4.52	3.3	2.99	3.29	3.3

TABLE X: Distractor Experiment (1 of 1)						Stimulus specifics: 1 .0 x threshold, ramp				
Subject		No Motion		Motion				No Motion		Motion
EPH	Avg RT	1.02		0.86		DDN	Avg RT	1.17		1.07
	StDev RT	0.43		0.3			StDev RT	0.53		0.48
	# Hit Trials	29		48			# Hit Trials	49		78
	# Miss Trials	3		0			# Miss Trials	22		2
	Contrast	14		14			Contrast	16		16
	d'	2.96		4.89			d'	1.34		2.79
	FA Rate	0.05					FA Rate	0.2		
DSG	Avg RT	1.44		1.29						
	StDev RT	0.52		0.43						
	# Hit Trials	29		28						
	# Miss Trials	8		12						
	Contrast	16		16						
	d'	2.01		1.75						
	FA Rate	0.11								
SYY Run 1	Avg RT	1.03		1.13		SYY Run 2	Avg RT	1.46		1.51
	StDev RT	0.4		0.4			StDev RT	0.5		0.5
	# Hit Trials	39		42			# Hit Trials	57		44
	# Miss Trials	1		0			# Miss Trials	35		29
	Contrast	13		13			Contrast	10		10
	d	3.14		4.43			d'	1.59		1.54
	FA Rate	0.12					FA Rate	0.1		

TABLE XI: Distractor Experiment (1 of 4)						1.5x Threshold, ramp				
SYY		Stim 1	Stim 2	Stim 3	Stim 4	Avg	Stim 5	Stim 6	Stim 7	Avg
Run 1	RT Mean	0.69	0.93	0.92	0.9	0.86	0.88	0.96	0.96	0.9
	RT StDev	0.18	0.34	0.34	0.52		0.34	0.52	0.31	
	# Hits	8	8	5	5	26	13	9	13	47
	# Miss Trials	0	1	2	1	4	0	1	0	1
	# Miss ID	0	0	0	0		0	0	0	
	# FA Trials	4		FA Rate = 0.22			# Blank Trials = 18			
	d'	4.01	1.99	1.33	1.73	1.88	4.01	2.05	4.01	2.79
SYY Run 2	RT Mean	1.22	1.46	1.45	1.13	1.32	1.12	1.19	1.15	1.14
	RT StDev	0.49	0.49	0.57	0.41		0.45	0.43	0.44	
	# Hits	17	14	12	10	53	14	20	9	58
	# Miss Trials	1	3	5	3	12	0	0	0	0
	# Miss ID	0	0	0	0		0	0	0	
	# FA Trials	0		FA Rate = 0.01			# Blank Trials = 21			
	d'	3.92	3.26	2.87	3.06	3.22	5.57	5.57	5.57	5.57
DDN	RT Mean	1.03	1.2	0.91	0.77	0.98	0.85	0.94	0.73	0.81
	RT StDev	0.4	0.5	0.41	0.23		0.34	0.39	0.21	
	# Hits	72	50	64	48	234	72	56	61	250
	# Miss Trials	2	16	1	2	21	1	4	2	7
	# Miss ID	0	0	0	0		0	0	0	
	# FA Trials	13		FA Rate = 0.11			# Blank Trials = 124			
	d'	3.17	1.95	3.39	3	2.64	3.43	2.75	3.1	3.17

To: tecohn @ mindseye.berkeley.edu AT INTERNET @ CCMNRC
From : Keith Gates
Date: 03/04/97 04:29: 17 PM
Subject: Final report for ITS-IDEA contract

Prof. Cohn

Looking through my old projects I notice that I still have to resolve a question on your final report to us. Sorry this has dragged on so long and I know we have talked about this before but the reviewer (Mike Perel at NHTSA) asked two questions about your report that have come up before and will come up again.

1) Why do you test at threshold visibility? To him this confuses the effects of threshold perception with the effects you are trying to test.

2) Is it the perception of motion or is it the perception of "flicker" that the subject is responding to? Your experiments make no attempt to determine which is the key element of the display. His contention is that you have not demonstrated that it is motion that is causing the effects you have measured.

I believe you have already put forth the reasoning on the threshold question in the report, and although I can see how the subject might be debatable, I don't feel there is a need to respond further in this report. You might possibly want to resolve this question with some further experiments but my understanding of your paper is that this methodology has this has been long established and that threshold testing is commonly accepted practice.

On the second issue, flicker vs. motion, it was suggested that a few paragraphs explaining how you have accounted for this effect (or not) would be a valuable addition to the paper. Since almost everyone who has seen this asks the same question I think it would be helpful if you could address it. If not, well OK, but let me know one way or the other so I can close out this contract and we can move on.

Yours, Keith Gates

To: Keith Gates
From: tecohn @ spectacle.berkeley.edu (Theodore E. Cohn) at internet@CCMNRC
Date: 03/05/97 02:20:00 PM
Subject: Re: Final report for ITS-IDEA contract

Keith:

Nice to hear from you.

I note that in tying up loose ends for my final report, two questions need to be addressed, the first having to do with the question of why use threshold level tests, and the second with the question of "whether subjects are seeing the flicker, not the motion." I appreciate the opportunity to reflect on these mainly because they are prompted by Mike Perel's reading of the report. He represents the target audience, is very perceptive, and I'm counting on him to have revealed any shortcomings that the work has.

The threshold question was dealt with in detail in the original proposal, and in the final report as you have noted, but maybe it needs some more detail here. One element of my concern has to do with your interpretation, an erroneous one which probably stems from my poor writing. The fact that people always do it this way is not the argument. The argument has two halves: one is that people always do it this way because this way gives quantitative objective answers and suprathreshold tests don't, unless one makes some questionable assumptions; the second half of the argument is that it is when the human eye is pushed to its limit that we have an interesting human factors test for situations that might arise in the real world. Stimuli that are easy to see are useful in modeling situations only when the sensory limitation doesn't matter. My research was specifically directed at an understanding of the sensory limitation. It's when stimuli are hard to see that we need to factor in idiosyncrasies of the sensory limitation. Suppose you're the driver. Your attention may be elsewhere, the vehicle may suddenly filled with smoke, you may have blinked or sneezed, or most common of all, you may simply be moving your eyes. Even this latter circumstance, like the others, takes highly visible signals and puts them near threshold. Threshold level is thus the test that matters.

Next for consideration is the flicker question. Sometimes, dragging things out a long time has its advantages. It also has disadvantages. I can now answer the flicker question as I understood it when you first raised it, but the new phraseology presents me with a new question. This original question is one which has occurred to audiences listening to a discussion of this research wherever it has been presented, it has occurred to you, and perhaps to Mike. It is answerable by extrapolation using data that have been previously gathered by others to estimate the so-called 'spatio-temporal contrast sensitivity function' for human vision. Those studies show that while stimuli with temporal or with spatial variation are better seen than steady or uniform stimuli, stimuli with both temporal and spatial variation (moving stimuli) are seen best of all. I cited one such study by Watson et al in my proposal. Extrapolation is fine, but one should not expect it to be convincing to a critical audience.

Just yesterday we took some data specifically related to the flicker question. But first I need to clarify what the question actually is. Up to now, when I've heard it, what I've heard being asked is whether subjects wouldn't do just as well with flicker, why go to the bother of creating movement? (Your more recent phraseology differs slightly - as I describe below.) But if this is the question, our new data answer it. While a MEWS target gave an average RT of .6+ seconds and a detectabiltiy of over 4.0, the same contrast in the same size flickering target gave avg. RT over 1.5 sec and detectability under 1 .0. Flicker proved to be far less effective in this instance.

If the question is whether subjects are "using" the perception of flicker (the going off of one piece of the moving target and the going on of the other) we have to admit we don't know. The data cited above suggest otherwise, but we cannot read the minds of our observers, nor would asking them help because that would lead to uninterpretable subjective impressions. For practical purposes, we, and virtually all other scientists in our field, look solely at the objective performance measures when they're available, RT and detectability. These make a compelling case for MEWS signaling. I would think that a prudent designer would adopt MEWS signaling strategies if and only if the objective measures point to an advantage. In this case they do.

Prof. Cohn