PSYCHOPHYSIOLOGICAL MEASUREMENTS AS RELATED TO THE OPERATION OF A MOTOR VEHICLE

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ABSTRACT

The purpose of the study reported herein was to determine the feasibility of using physiological parameters as a source of design criteria for the highway visual communication environment. Source material was reviewed, and a model for relating physiological performance, driver behavior, and highway design features was introduced and evaluated on the basis of previous research. It was concluded that the model, because of its measurable parameters, could be used in evaluations of the general roadway environment. It was not recommended for evaluation of a specific design feature. Specific design features to which the model could be sensitive would not likely exist in the roadway environment because of the professional competence of the highway design engineer. The physiological indices considered applicable to the objective of this study were identified, and the manner in which they might be used was briefly presented.

SUMMARY

Current trends in the operation of the Roadway/Vehicle/Driver System have placed complex design requirements on all of the system components. State-of-the-art advances in knowledge about each component will be necessary to meet these requirements. One of these components is the driver. Although the driver can be considered from the standpoint of physiological factors, psychological factors, and man-machine performance, this paper deals only with physiological factors. The purpose was to determine the feasibility of using physiological parameters as a source of design criteria for the highway visual communication environment. To accomplish this purpose, several authoritative sources on physiological parameters were reviewed, and a general model for relating physiological performance, driver behavior, and highway design features was developed. Using the model as a framework, the utility of several physiological indices was discussed using past research as criteria.

The conclusions of this study are as follows:

(1) The level of arousal model is a logical framework within which physiological parameters can be related to vehicle operations.

(2) The physiological parameters suited to this model are measurable and sensitive to the general roadway context. As yet, their sensitivity to a specific design feature present on the roadway has not been demonstrated.

(3) The feasibility of recording the driver's physiological

performance in the highway environment depends largely upon economics. The necessary recording and subsequent data reduction can be costly; therefore, cost-effectiveness studies should be conducted.

(4) Depending upon their feasibility, these parameters could be used as a supplementary means of evaluating the general roadway environment as a whole. The criteria would be deviation from comfort arousal baseline and the normal band of arousal for behavior performance. These physiological parameters may be applicable to assessment of stress and evaluation of the onset of fatigue.

(5) Also, physiological parameters may be used as a means of assessing the general design goals of the highway visual environment. Arousal should remain within acceptable limits, when the roadway is being used as it was designed; thus, the designer has achieved one of his goals. If the roadway is being used in ways for which it was not intended and arousal exceeds normal limits, the design engineer may not be at fault. A measure which could differentiate between these conditions would certainly be valuable.

(6) The physiological indices which appear immediately applicable include heart potentials, relative blood pressure, body temperature, and respiration rate. Brain potentials and Galvanic Skin Response have, in the long run, the greatest

potential; however, some minor problems associated with their use still exist. These problems can be solved within the present state-of-the-art, but to the authors' knowledge they have not been resolved to date. Muscle potentials and eye movements as pure physiological responses do not at this time appear useful.

(7) Future studies of physiological parameters should be directed toward the definition of the comfort arousal baseline and the normal arousal band which can serve as standards for general roadway evaluation.

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1.0 INTRODUCTION

1.1 PROBLEM

The growth and affluence of the American public have led to an increase in the number, types, and usage of motor vehicles. This increase, coupled with today's highly flexible society, has provided the capability and desire for rapid mobility. Despite advantages offered by these changes, all of the results have not been satisfactory. To name a few, roadway features are being made obsolete prior to completion of design life; highways are frequently overcrowded; vehicle operation is more demanding, and there appears to be a wave of unending public pressure to push highway speeds higher and higher. From the safety and economic standpoints, these current trends have placed complex design requirements upon and taxed the capabilities of all components of the Roadway/Vehicle/Driver System. Meeting these requirements in many cases will entail state-of-the-art advances in knowledge about each system component.

Of primary concern in this report is the highway visual communication environment and its interaction with the driver component of the Roadway/Vehicle/Driver System. Only limited information is available about this component, and pinpointing those factors of driver performance which could serve as roadway design criteria is no easy task. It is felt, however, that such information will eventually come from the study and measurement of physiological parameters, psychological factors, man-machine performance measures, or all three.

1.2 PURPOSE AND OBJECTIVES

The purpose of this report is to determine the feasibility of using physiological parameters as a source of design criteria for the highway visual communication environment. Specific objectives are as follows:

(1) To formulate a theoretical basis for relating physiological performance, driver behavior, and highway design features.

(2) To identify the physiological parameters pertinent to the operation of a motor vehicle.

(3) To examine the design utility of these parameters on the basis of results of previous experimental studies.

(4) To present specific conclusions and recommendations regarding their application to subsequent diagnostic studies of the highway visual communication environment.

2.0 APPROACH

The following sequence of steps defines the approach used to accomplish the objectives identified in Section 1.2:

(1) Several authoritative sources on physiological parameters were identified and reviewed.

(2) From this review, a general model for relating physiological performance, driver behavior, and highway design features was developed and discussed.

(3) A listing of physiological measures pertinent to the general model was derived, and definitions of these measures suitable to the purposes of this report were summarized.

(4) Using the listing as a guide, studies previously conducted in which driver performance was correlated with physiological measurements, were examined.

(5) Finally, conclusions regarding the utility of physiological indices were drawn, based upon the review of these studies.

3.0 RESULTS OF STUDY

Results of the study are summarized in the following sections labeled A Physiological Model and Physiological Indices. The first provides a framework for understanding the relationshop between physiological performance, driver behavior, and highway design features. The second defines the physiological indices which appear relevant to motor vehicle operation and its interaction with the highway visual communication environment.

3.1 A PHYSIOLOGICAL MODEL

One of the general factors important to understanding and predicting driver-vehicle performance is perceptual alertness. It is a psycho-physiological mechanism, which simply means the degree to which an individual can efficiently attend to, receive, and interpret information from the ambient environment. One primary factor upon which perceptual alertness depends is the individual's level of arousal. Level of arousal is associated with the reticular activating system and in a gross sense can be considered as potential energy for behavior. A graphical plot of the relationship between perceptual alertness and level of arousal would look like a horseshoe. As arousal changes from low levels of relaxed sleep through intermediate levels of normal consciousness to high levels of stress, perceptual alertness increases to a point, levels, and then decreases. Table 1 provides additional insight into the nature and meaning of this relationship. More comprehensive treatments of perceptual alertness are presented by Hebb (11) and Berlyne (2).

Aside from physical ability or well-being, the importance of perceptual alertness to motor vehicle management in the highway environment is readily

TABLE I

A TABULAR DESCRIPTION OF THE RELATIONSHIP BETWEEN

LEVEL OF AROUSAL, PERCEPTUAL ALERTNESS, AND OTHER ASSOCIATED FACTORS

Level of Arousal	Physiological State	General Causative Factors	Degree of Perceptual Alertness and Corresponding Effect on Behavior
Low	Sleep or highly relaxed condition	Biological requirements associated with rest and recuperation are operating here.	Perceptual alertness is very low for attention and interpretation. Stimuli of high intensity levels will be received, but are not likely to be interpreted correctly. Behavior is sluggish, and correlation with external stimuli is low.
Intermediate	Normal consciousness	External requirements of the ambient environment serve as stimuli to mobilize the individual; these stimuli can be either real or perceived.	Perceptual alertness is high, correlation between behavioral responses and external stimuli is high, and behavior can be expected to be suitable for handling daily task activities.
High	Stress	External requirements of the ambient environment call for performances which exceed or threaten to exceed the individual's capabilities.	Perceptual alertness is degraded; individual has difficulty in selectively attending to and interpreting the important environmental factors upon which his behavior should depend. Behavior is erratic, undependable, and not suitable for meeting the situational requirements.

apparent. Low perceptual alertness would reduce driver effectiveness and increase hazards of vehicle operation. Generally, high perceptual alertness would result in desired driver performance. Despite this importance, its utility as a mechanism for deriving design criteria for the highway visual communication environment depends upon whether or not it can be measured.

To understand one potential means of measurement, it is necessary only to return to the fact that perceptual alertness depends upon level of arousal. Important in this respect is that researchers (11) and (2) have shown that level of arousal can be indirectly measured using physiological indices. Of course, this means that the suggested indices would be twice-removed from perceptual alertness; however, they still appear to be relevant measures of this important mechanism. Figure 1 was prepared to demonstrate this relevancy. Although the operation shown here is highly simplified and somewhat theoretical in nature, a substantial basis for its formulation has been provided by behavioral scientists (11, 2, 4).

There are several inferences, pertinent to the purpose of the present study, which can be drawn from the model in Figure 1.

(1) This is a model, the underlying components of which can be measured.

(2) There is a normal band of arousal within which perceptual alertness is high and equal throughout. Outside the limits of the arousal band, perceptual alertness is low.

(3) Within the normal band of arousal, there is a baseline arousal level for handling situational tasks. From the standpoint of comfort, this is likely the level at which an individual prefers

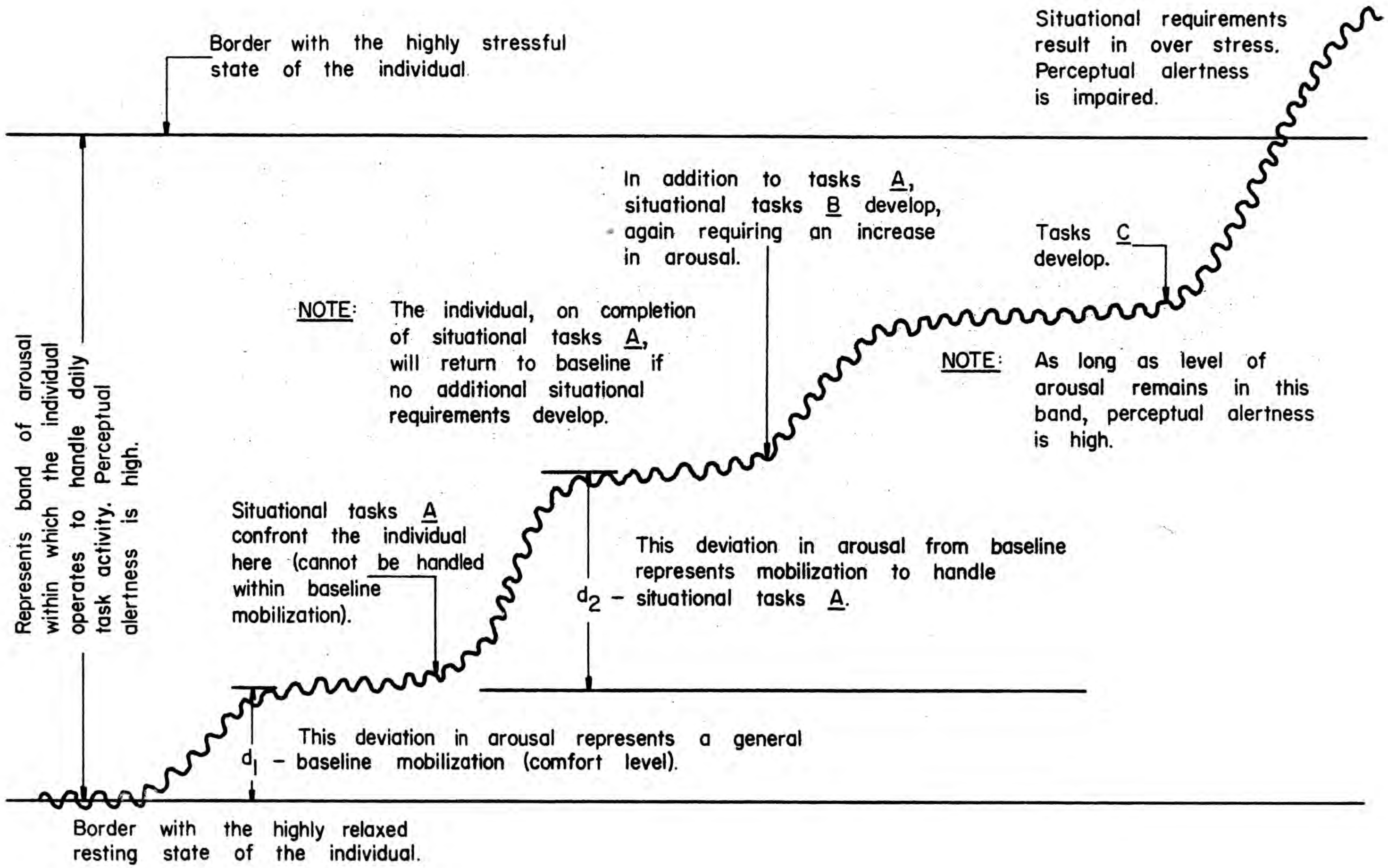

FIGURE 1

A HIGHLY SIMPLIFIED GRAPHICAL REPRESENTATION OF THE RELATIONSHIPS BETWEEN PHYSIOLOGICAL INDICES, LEVEL OF AROUSAL, AND PERCEPTUAL ALERTNESS to operate.

(4) Situational "real life" tasks can require deviations from the comfort baseline; however, as long as arousal is within the normal arousal band, situational requirements can be handled by the individual. The magnitude of the deviation is probably an indicant of reduced comfort and the rate of onset of fatigue.

(5) A single situational task or combination of tasks can present requirements which cause arousal to exceed the normal band. In this case, perceptual alertness decreases, and the individual's performance is degraded.

Several investigators have the general hypothesis that roadway design features impose requirements upon the driver which induce physiological changes. If this hypothesis is coupled with the inferences drawn from the model shown in Figure 1, several design implications can be formulated.

(1) Deviations from the comfort baseline resulting from roadway design features could be scaled and used as supplementary criteria in roadway design evaluation.

(2) An important design engineering goal would be to minimize deviation from the comfort baseline.

(3) The final level of arousal required by general roadway design features should be well within the normal arousal band. Adequate arousal reserve must be potentially available to the driver for handling emergencies.

Again, it must be recognized that the value of the model and associated implications depend upon measurement. From the standpoint of validity, this measurement should be accomplished under operational conditions or at least conditions closely approximating the operational situation. The various physiological indices which can serve as measurement tools, and at the same time appear potentially feasible for operational situations, are discussed in the following section.

3.2 PHYSIOLOGICAL INDICES

Several different sources provided information for this section. Initially, a single medical source (10) was selected. Since a cursory examination of several medical physiology books revealed a large degree of duplication, selection of a single book was satisfactory for the purposes of this report. To gain additional insight, other informational sources were examined, which included the following: a behavioral psychology handbook (15), an aerospace technical document (1), and a text on physiological measurement (3). Other journal articles serving to amplify specific factors associated with physiological indices also were examined. The final source of information for this section included previous studies in which physiological indices were used to measure driver performance.

3.2.1 Brain Potentials and Electroencephalography

The recording and evaluation of electrical potentials generated by the brain and sampled at the scalp surface is called electroencephalography. The graphic record is called an electroencephalogram (EEG). Results of EEG records show that when an individual is relaxed, brain waves are characteristically low in frequency and high in amplitude, and the two primary characteristic wave forms have been designated as the Alpha and Beta rhythms.

These basic rhythms are important to this discussion because they essentially represent a baseline of relaxed condition, and an individual's level of arousal is directly related to changes in these wave forms, such that frequency is increased and amplitude is decreased.

Operational requirements associated with a general situational task or the startle resulting from a single stimulus object cause measurable changes in an individual's brain potentials. These changes in turn correlate with his behavioral response to the task or stimulus. It is precisely this relationship which has been of interest in aerospace medicine. The conclusion is that brain wave activity is a measurable index of the state of alertness of an individual exposed to the stresses of the aerospace environment (1). This being the case, EEG would potentially have application to the study of driver performance.

Despite its apparent utility for studying certain problems of motor vehicle operation, no study could be found in which EEG had been used. It has been suggested that the electrical noise of the driving environment would hamper the small signal requirements associated with recording brain waves (12).

Others have pointed to problems of interpretation (22,23). A more recent treatment of EEG, however, suggests that these problems have been resolved with new equipment and magnetic tape recording techniques (1,3). If this is true, it is apparent that EEG could be used to study the stress caused by various roadway situational contexts. As a method for studying a single design feature of the roadway, EEG does not, however, appear useful. It seems unlikely that design features which induce driver startle would ever knowingly get beyond the highway engineer's drawing board, if that far.

3.2.2 Heart Potentials and Electrocardiography

The electrocardiogram (ECG) is a graphic trace of electrical heart potentials measured at the body surface, and it is one of the most useful indices of cardiovascular function (10). Electrocardiography as a clinical technique has well-established norms based on millions of measurements. In addition to its utility for diagnosing cardiac disease, it has also been employed as an indicant of environmental stress and as an index or overall alertness, especially when used in conjunction with blood pressure and respiration (1).

Heart rate which can be read directly from the ECG record is a good index of arousal; however, its large latency places some restriction on its practical usage in the study of vehicle operation. Latency refers to the time required for a measurable change to occur, given a stressful stimulus condition. This suggests that heart rate would not be a practical index for taking measurements within short time frames. It is additionally apparent that this large latency would also preclude using heart rate to study the stress effects caused by a single stimulus object in a larger situational context. By the time a change in heart rate occurred, it would not be possible to ferret out any single stimulus object from a multitude of objects as having caused the change. To resolve the problem of latency, one investigator (28) suggested the use of the following: (a) heart rate acceleration, the maximum rate of change in heart rate after occurrence of the stimulus object; and (b) heart rate change, the average of the fastest and next succeeding heart beat. Although these seem feasible, they have not, to the authors' knowledge, proven to be very successful.

It must be concluded that heart rate is best suited for measuring the level of arousal resulting from a general situational context. Driver performance studies in which heart rate was recorded generally support this conclusion (15, 18, 19, 20, 25). With this relationship so reliably verified, future application of heart rate measures to roadway design should relate to their use as a method for comparing general roadway contexts with one another, or for development of an acceptable heart rate standard for general roadway evaluations.

3.2.3 Muscle Action Potential and Electromyography

Electromyography is the technique of measuring and recording the electrical potentials in the muscle fibers associated with muscular contraction. The resulting graphic is called an electromyogram (EMG). Surface electromyography (i.e., measurements taken with body surface electrodes) has been used to evaluate movement patterns and physiological fatigue of specific muscle groups. Although its logical relationship with general stress has been suggested, no specific conclusions have been drawn (15).

If it were feasible to place electrodes on the surfaces of all major muscle groups, the resulting output may well correlate with general arousal and thus prove useful in the study of general roadway conditions. This, of course, is impractical and very likely impossible. To the authors' knowledge, whether or not the output from a selected sample of muscle groups would be valid as a prediction of general arousal has not been adequately substantiated. Therefore, the current status of EMG would indicate that it is too specific to singular muscle groups to be an overall indicant of either arousal or even general fatigue.

A single study (20) of driver performance was found in which EMG records were obtained; however, this proved to be only a feasibility study, and no meaningful generalizations were drawn. It has been suggested that one of the problems associated with the use of EMG is that most frequencies of interest are generally too high to be recorded with direct-writing instruments; however, magnetic tape recording techniques have resolved this problem (1). In conclusion, it should be pointed out that the applicability of EMG data for generalizing to the status of the total individual has not yet been demonstrated. This precludes drawing hard conclusions concerning its utility in the study of driver-vehicle operations.

3.2.4 Respiration

A close relationship exists between an individual's respiratory system and changes in his level of arousal. Although respiration is an area of research particularly suited to the investigation of stress, few investigators have made respiration a major topic of interest. This may be due to the complex nature of respiration, which includes ventilation, gas diffusion, pulmonary circulation, and gas transport in the blood, as well as the mechanics of breathing.

Respiration used singularly is especially sensitive to stimulus objects which startle the individual, but, when coupled with other physiological indices, it becomes a good indicant of general level of arousal. As mentioned previously in the discussion of EEG, the study of single design features of the roadway using indices sensitive to startle are likely to be of little value; therefore, the utility of respiration depends upon its being coupled with other measures of arousal. This conclusion has been generally verified (18, 19).

3.2.5 Temperature

Body temperature is one of the most valuable indices of stress and overall level of arousal. In aerospace applications, its measurement is a vital part of continuous monitoring from stressful environments, and it is included in most physiological monitoring systems (1). Like heart rate, body temperature has a large latency, and like heart rate is is neither suitable for the study of single features of the environment nor for studies in which short time frames are a requisite. If the time frame for data collection is sufficiently long, temperature, like heart rate, would be a good indicant of arousal changes resulting from the general roadway environment. No studies were found in which body temperature was used to study driver performance.

3.2.6 Blood Pressure

The pressure of the blood in the great arteries is one of the most significant indices of cardiovascular function (10) and arousal (15). Blood pressure is determined by several interacting factors, including blood viscosity and the elasticity and diameter of blood vessels. Like the electrocardiogram, the measurement of blood presure is a standard clinical technique with well-established norms and, as such, it is generally considered one of the more valuable and necessary parameters for an aerospace monitoring system.

There are two measures of blood pressure, systolic and diastolic. Systolic is a measure of the maximum pressure reached during heart contraction, and diastolic is a measure of the least pressure during heart expansion. Of the two, systolic pressure is the best indicant of arousal. Although it cannot be measured continuously, many experimenters have accepted a compromise which takes measures of pressure changes from a predetermined standard (15). This latter measure is called relative blood pressure, and it has proven to be a useful indicant of level of arousal.

Three studies were found in which blood pressure was recorded as a measure of driver performance (16, 18, 19). The general conclusion, in each case, was that blood pressure could be linked to level of "excitation" or arousal, but that variations in this measure must be interpreted with respect to some baseline arousal level. Apparently, blood pressure is similar to heart rate, and can probably not be successfully applied over a short time period for the same reasons previously cited for measures of heart rate.

3.2.7 Ocular Potentials

There are two standard electrical techniques for measuring ocular potentials. One is the electroretinogram, which is a measure of potential differences between the cornea and the retina of the eye; the other is the electro-oculogram, which measures changes in the ocular muscles as a result of eye movement. Although the relationship between these measures and level of arousal seems plausible, their significance as indicants of arousal is simply not known (1,15).

Some investigators have suggested that the latter measure, eye movement, provides relative indications of alertness (1) and stress (17). The emphasis in these studies is placed on frequency and distance of eye movement. No studies of driver performance measured by ocular potentials were found. It must be concluded that evidence supporting the utility of this measure as an indicant of arousal has not been developed; therefore, its practical application in driver-vehicle field studies, where general level of arousal is of primary interest, is not recommended at the present time.

It should be noted that this conclusion in no way reflects on the utility of eye movement as recorded by the eye-mark camera. In this case, valuable data are provided on both eye scan patterns and object fixation times, which are important factors in determining significant driver cues in the highway visual communication environment.

3.2.8 Galvanic Skin Response

Galvanic Skin Response (GSR) is a relatively slow change in the electrical resistance of the skin measured between two points. The GSR and the electroencephalogram are the two most important indices of level of arousal (1). Evidence shows that the amplitude of GSR, or rise in skin conductance, is a valid predictor of general alertness, and this amplitude is particularly sensitive to stimulus objects in the environment which induce stress (6, 8, 20, 22, 28).

The GSR has probably been studied and used as a physiological response more than any other single parameter. The results of many of these studies have pointed out the problems associated with its variability, measurement, and interpretation. Concerning variability, experimenters point to amplitude and latency (9, 26), to anticipatory changes (21, 26, 28), to baseline drifts (19, 24), and to random, and/or uncontrolled artifacts (8, 17, 27). With respect to measurement, experimenters point to difficulties associated with electrodes (1, 9), the use and magnitude of a signal conditioner (1), and measurement recording rates (7). Problems of interpretation usually relate to the several features of the GSR wave form and the determination of their meanings (13, 17, 26, 28). Referring to these past studies at this point in time, it is evident that several of the problems resulted from the state-of-the-art at the time they were conducted (3). In addition, similar types of problems existed, or would have existed, at the same point in time for most of the other physiological parameters. Finally, it can be concluded that, although all of these problems and their associated idiosyncracies have not been resolved, GSR is nevertheless obtainable, and its validity as an indicant of arousal is generally accepted.

As one would expect, several studies in which GSR was recorded to measure driver performance have been conducted. Again, as one should expect, there are conflicting results because many have been bothered with the same types of problems mentioned previously. A review of these studies is not, therefore, considered to be relevant to the purposes of this discussion. What is significant is the fact that GSR is a valid indicant of arousal (2), and it is both measurable and interpretable (1,3). Like the electroencephalogram, GSR, used appropriately, should provide a ready assessment of changes in arousal as a function of the general roadway environment; however, its utility in assessing arousal as a function of a single design feature of the roadway has not been established.

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