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ALCOHOL EXPERIMENTS ON DRIVING-RELATED BEHAVIOR: A REVIEW OF THE 1972-1973 LITERATURE-ALCOHOL COUNTERMEASURES LITERATURE REVIEW

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16. Abstract

Liberal consumption of alcoholic beverages influences driving behavior. There is universal agreement of this fact, but there is less consensus on the specific nature of the assumed influences of alcohol and far less experimental evidence for the exact nature and scope of such effects.

The purpose of the author's review is to present and critically discuss some recent experiments concerned with influences of alcohol upon behavioral variables which are assumedly relevant for successful driving performance.

This review is limited to laboratory experiments (including part-task simulator studies) in which: (1) alcohol was either the only drug or at least the primary drug investigated, (2) healthy (i.e., non-alcoholic) subjects were used, and (3) those aspects of behavior that seem more immediately involved in driving were investigated.

The author summarizes by considering important trends which have been developing and/or culminating in recent years, the research needs suggested by recent reviewers, and a listing of recent investigation in which specialists rated priorities for basic research and applied research in the area of alcohol and highway safety.

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CONTENTS

ALCOHOL EXPERIMENTS ON DRIVING-RELATED BEHAVIOR: A REVIEW OF THE 1972-73 LITERATURE[1]

There is probably almost universal agreement that driving behavior is influenced by liberal consumption of alcoholic beverages, at least in some individuals -- usually "the other guy." However, there is considerably less consensus on the specific nature of these assumed influences of alcohol -- and far less experimental evidence for the exact nature and scope of such effects. The primary purpose of this review is to present and critically discuss some recent experiments concerned with influences of alcohol upon behavioral variables which are assumedly relevant for successful driving performance. More specifically, it is concerned with those particular aspects of behavior which are actually impaired by alcohol and which, consequently, appear to increase the likelihood that the driver will be involved in a crash. The rationale for selecting the particular aspects of behavior which are assumedly relevant is discussed below as one of the most important issues in this area of research.

METHODOLOGICAL CONSIDERATIONS

The range of behaviors potentially encompassed by the primary purpose of this review is very extensive. As a maximum, it could extend from alcohol influences upon neurophysiological and neuromuscular activities through the full spectrum of the more psychological processes (e.g., sensory, perceptual, attentional, cognitive, learning, motivational, etc.) and emotion, mood, and personality characteristics, to alcohol influences in combination with other stressors (e.g., fatigue, noise, other drugs, etc.). Since the scope of the literature on this broad range of topics is enormous, it was necessary to be quite selective. Accordingly, this review is limited to laboratory experiments (including part-task simulator studies) in which: (1) alcohol was either the only drug or at least the primary drug (or other stressor) investigated, (2) healthy (i.e., non-alcoholic) subjects were used, and (3) those aspects of behavior that seem more immediately involved in driving were investigated.

The organizers of this report set further constraints on each author to provide a focused critical review that would be selective and evaluative rather than exhaustive and reportorial. Thus, many studies located during the course of the literature search have been excluded from this review on the basis of one or more of the above considerations. More specifically, all the studies located were evaluated in terms of two criteria: primarily, on the merit and relevance of the problem investigated; and secondarily, on the adequacy of the experimental design and procedures, i.e., the extent to which it would support the inferences and conclusions offered by the investigators.

The survey of the literature pertaining to this review included publications which appeared between January 1972 and December 1973, as determined by termination of the search in February 1974. The major sources for the literature search included 13 research journals, 6 journals of abstracts, and 6 published proceedings of symposia or conferences.[2] In addition, 2 computerized searches were requested: PASAR[3] and NIAA/NCALI.[4] Regarding the results of the literature search, 132 apparently relevant titles were identified, of which hard copy was obtained for all but 5. The vast majority of these titles designated original reports of experiments, although 16 publications consisted of reviews. Most of the publications were written in English, but 26 were in German and 1 was in French. Approximately 30 of the 111 obtained reports of experiments were selected for inclusion, in addition to the 16 review articles which are treated separately below.

GENERAL REFERENCES AND REVIEWS

The present report represents an attempt to provide the first annual review of literature in related aspects of alcohol, drugs, and highway safety; thus, it seems both appropriate and useful in this chapter to cite not only the recent, but also the more important earlier reviews of alcohol and behavior. A number of surveys of this literature have been published over the years, ranging from the first comprehensive review of Jellinek and McFarland (1940) and other earlier but less extensive reviews by Darrow (1929) and Marshall (1941), to the series of four articles appearing in French in the 1946 edition of Schweizerische Medizinische Wochenschrift (cited in Wallgren & Barry, 1970, p. 276), to the recent and by far the most comprehensive review by Wallgren and Barry (1970). With the exception of the latter work, recent reviews tend to be quite specialized and thus limited to specific aspects of behavior, of which the following are potentially relevant for the present discussion: influences of alcohol upon neurophysiological activity (Kalant, 1970; Perrine, 1973a, 1974e) and in particular upon the neuron (Grenell, 1972, the autonomic nervous system (Naitoh, 1972) and the central nervous system (Begleiter & Platz, 1972), as well as upon the more psychological processes such as attention and perception (Carpenter, 1962; Huntley, 1973a, 1974; Moskowitz, 1973a, 1973b, 1974; Perrine, 1973a, 1973b, 1974e), motivation and cognition (Barry, 1973, 1974), aggression (Carpenter & Armenti, 1972), sleep (Williams & Salamy, 1972), tension reduction (Cappell & Herman, 1972), and perhaps even sexual behavior (Carpenter & Armenti, 1972).

A limited number of surveys specifically concerned with alcohol experiments and driving-related behavior have been published over the years. The earliest and one of the most comprehensive was written by Carpenter (1962) and was followed by a more specialized article a few years later (Carpenter, 1968). Another comprehensive review of the experimental literature (in addition to the epidemiologic literature) was included in the AMA's manual on Alcohol and the Impaired Driver (1968). A brief review of some of the same experiments can also be found in USDOT's report entitled, Alcohol and Highway Safety (1968). Some of the earlier experimental literature has also been included in Martin's (1970) overview of alcohol and driving; and an extremely limited consideration of a few alcohol experiments was offered by Buttiglieri, Brunse, and Case (1972) in a review which primarily emphasizes the epidemiologic evidence for alcohol involvement in highway crashes. Some of the German literature concerning alcohol impairment and highway safety has recently been reviewed by Heifer (1972), but he has focused more on the medico-legal than on the experimental.

In an attempt to remedy the absence of comprehensive up-to-date reviews of the growing body of relevant literature, the "Vermont Symposium on Alcohol, Drugs, and Driving" was conducted in October 1972; one of its specific aims was to provide systematic evaluative reviews of the eight major aspects of these two problem areas, with each review written by a leading specialist in that aspect. Four of these reviews are especially relevant for the present survey, and in one sense, they are its immediate predecessors. Behavioral aspects assumedly relevant for on-the-road driving performance were divided among three of the specialists. Thus, influences of alcohol upon neurophysiological, neuromuscular, and sensory aspects of behavior were reviewed by Perrine (1973a, 1974e). Moskowitz (1973b, 1974) considered alcohol influences upon sensory motor aspects of behavior, visual perception, and attention. Barry (1973, 1974) was concerned with alcohol influences upon memory, learning, cognition, motivation, emotion, and mood. The fourth paper was concerned with alcohol influences upon closed-course driving performance (Huntley, 1973b, 1974). These and some of the other reviews were published in a special issue of the Journal of Safety Research in September 1973, but all the reviews, proceedings, and other material from the Vermont Symposium have recently been published in one volume (Perrine, 1974b). It should also be noted that a review of experiments concerned with alcohol influences upon performance in driving simulators was presented earlier at a related symposium by Heimstra and Struckman (1972). These five papers, then, constitute the immediate background for the present survey, although the amount of overlap is minimal due to the different time periods involved.

Special attention should be called to an innovative and laudatory attempt not merely to review, but systematically to classify and integrate the research findings concerning alcohol effects upon human performance. Building upon an earlier demonstration of the usefulness of a task classification approach for organizing an area of research literature (e.g., vigilance, drugs), Levine, Greenbaum, and Notkin (1973) attempted to apply to the alcohol literature a classification system or taxonomy of performance based upon human abilities. According to the authors, the general goals of their efforts to achieve a systematic structuring of the data concerning these alcohol influences were to: "(a) integrate apparently disparate and isolated results, (b) improve generalizations across experimental studies, (c) identify gaps in the existing literature, and (d) identify new relationships among independent variables and performance (Levine et al., 1973, p. 1)." They also stated that their effort was designed in part to categorize the existing literature into task groups in order to determine whether or not the effects of alcohol differ as a function of different types of tasks.

The particular abilities required to perform different tasks were derived from factor analyses of human performance data; as a result, 37 abilities were identified, operationally defined, and categorized into cognitive, psychomotor, perceptual-sensory, and physical domains. The extent to which each of these abilities is required for a particular task performance was then determined by a set of rating procedures. On the basis of their review of the alcohol literature, the authors found that tasks requiring abilities falling into the cognitive, perceptual-sensory, and psychomotor domains were the most frequently occurring. The specific set of abilities chosen to represent these three domains also consisted of the most frequently occurring in the literature, namely, selective attention, perceptual speed, and control precision.

One serious conceptual limitation to their approach should be clearly noted at this point; in defining selective attention for the purposes of their classification scheme, the authors unfortunately include both selective and intensive attention. As discussed below, sufficient experimental evidence is already available to indicate reliable differences in alcohol influences upon these two functionally different types of attention. Thus, Levine et al. (1973) may unwittingly have introduced an avoidable source of variance in their otherwise commendable analysis. The clarity of their results would doubtless be improved if the data were re-analyzed with the two types of attention treated separately; this should be possible since the authors reported that in terms of specific abilities, the greatest single proportion (44%) of tasks were classified as requiring selective attention as the predominant ability (p. 17).

Levine et al. (1973) uncovered 179 relevant studies and after careful screening, selected 62 for further evaluation which in turn reduced the final data base to a set of 41 studies, in which 165 independent tasks were represented. The authors' choice of independent variables for their analyses was based upon the frequency with which the variables were studied in the literature, the most frequent being dosage and time. In the absence of any single performance measure obtained in the different behavioral areas represented in the literature, the authors found it necessary to derive a common dependent variable to facilitate comparison of data across studies. Percent difference was used as their dependent variable and was defined as the difference between the scores for the experimental and control conditions, divided by the control-condition score, and multiplied by 100%.

The results are perhaps best summarized in the authors' own words:

> The data suggest that the curves relating performance to dosage differ as a function of the ability requirements of the task. Further, the effects on performance of length of testing period and time between alcohol administration and the initiation of testing were marked and depended upon the abilities required by the task. In each case, different functional relationships were evident. Overall, psychomotor tasks appeared to be least impaired by alcohol and perceptual-sensory tasks appeared to be most impaired. Cognitive tasks fell in-between. Performance deteriorated more rapidly and was impaired to a greater degree when the testing period was less than one hour than when it was one hour or greater. Further, cognitive tasks were most impaired in shorter testing periods but perceptual-sensory tasks were most impaired in longer testing periods. The greatest impact of alcohol upon performance occurred when an hour or more was permitted to elapse between the administration of alcohol and the initiation of testing. ... When testing was initiated within 30 minutes of alcohol administration, the impact of alcohol appeared to be minimized.
>
> Despite differences among the specific tasks in terms of displays, response requirements, performance index, technique of alcohol administration, etc., the categorization of tasks according to ability requirements enabled an integration of results and the development of functional relationships which otherwise were obscured. (Levine et al., 1973, p. 29)

Finally, Levine et al. (1973) discuss several important directions for future research and offer several recommendations. On the basis of their analysis of the alcohol literature, the authors feel that research on the following topics would be highly desirable: (1) practice effects, especially the extent to which alcohol affects the practice curve during the acquisition of learned performance; (2) time parameters, especially the effects -- as independent variables -- of the length of testing and the elapsed time between dosage administration and the initiation of testing (which they found affected the relationship between performance and dosage); (3) the experimentally manipulated interaction of dosage and time as an influence upon performance; and (4) the effects of alcohol upon task performance of heavy drinkers and alcohol-dependent individuals. Levine et al. (1973) also recommended that alcohol research "should be concentrated on the tasks which tap some underlying behavioral mechanism, such as attention, memory, etc., and which simulate aspects of performance which are commonly required in real-life situations (p. 29)." They also thoroughly endorse the calls of earlier reviewers (Jellinek & McFarland, 1940; Carpenter, 1962; Wallgren & Barry, 1970) for standardization of research methodology in studying alcohol influences:

> The goal is to standardize subject populations, dosage administration technique, dosage index, type of alcohol, etc., in order to make findings more comparable to one-another. A sometimes neglected but very important consideration is the need to employ indices of performance which are commonly used in psychological research. Two such indices are accuracy and speed of performance. Of the studies included in this effort, only 5% reported accuracy scores and only 23% reported latency. Future research would be more useful if these indices were more frequently used. (Levine et al., 1973, pp. 30-31)

In conclusion, it is hoped that these recommendations of Levine et al. (which are heartily endorsed) will be heeded by the appropriate alcohol agencies and investigators. It is also hoped that this novel and promising approach will receive wide circulation to maximize its important heuristic potential. Finally, it should be emphasized that this systematic, post hoc analysis of the alcohol literature by Levine et al. provides strong support for the notion recently broached by Barry (1973, 1974) and by Perrine (1973a, 1974e) that a matrix of integrated, parametric studies designed and conducted in conjunction with one another would have greater value and impact than the cumulative contribution of a number of isolated independent studies of the usual small-scale variety.

CURRENT PROBLEMS

In reviewing the recent literature concerning alcohol experiments on driving-related behavior, one cannot help but be impressed by a number of recurring problems and issues. Although many of these are highly intertwined, the more salient aspects can be identified. Unfortunately, it is not possible within the scope of the present review to examine any of these aspects in great detail. However, each is either discussed briefly or references to recent expositions are provided. In either case, it is sincerely hoped that structuring them in the present context may help focus corrective attention on them.

The five most salient aspects of pervasive current problems can be expressed in terms of: (1) the actual contribution of alcohol to highway crashes; (2) relative to alcohol effects, what behaviors are relevant for driving; (3) what is impairment, and what are the <u>behavioral</u> criteria for impairment; (4) individual differences in response to alcohol; and (5) the lack of models (whether operational, empirical, conceptual, or mathematical).

Considering these aspects in reverse order, the question concerning the lack of models is examined below in the final section of the present review. Regarding individual differences, methodological issues concerning behavioral variability in alcohol research has been treated extensively by Perrine (1973a, 1974e). Additional discussions of the importance of individual differences in alcohol effects have been provided by Barry (1973, 1974), Carpenter (1968), Huntley (1973a, 1974), and Wallgren and Barry (1970). The nature of alcohol impairment of driving and driving-related performance has been extensively analyzed by Huntley (1973a, 1974). The interrelations of the first three problem aspects (concerning the actual contribution of alcohol to highway crashes, driving-relevant behaviors, and behavioral criteria for impairment) have been examined by Perrine (1973a, 1974e) and are also considered in the following section, with relatively greater emphasis on the first point.

Finally, by way of relating the reviewed research and the current status of these interrelated problems to future needs and priorities, a few major trends which have been developing and culminating in recent years are discussed below in the concluding section.

ALCOHOL AND HIGHWAY CRASHES

The contribution of alcohol to highway crashes has been inferred from two different types of data: epidemiologic and experimental. On the one side, alcohol has been seriously implicated in fatal and serious injury crashes -- after the fact -- by epidemiologic studies (recently reviewed by Hurst, 1973, 1974; Perrine, 1974a; Stroh, 1972, 1974; and Zylman, 1971, 1974). On the other side, influences of alcohol upon driving and driving-related behavior have been systematically observed using experimental subjects performing contrived psychophysical, sensory-motor, and driving tasks in laboratories and on driving ranges (reviewed recently by Barry, 1973, 1974; Huntley, 1973a, 1974; Moskowitz, 1973b, 1974; and Perrine, 1973a, 1974e). From these epidemiologic and experimental studies, it has frequently been inferred that alcohol degrades a driver's capabilities -- and, consequently, his actual driving performance -- such that the probability of his being involved in a crash is greatly increased.

If the assumption is correct that alcohol does degrade a driver's capabilities and performance, then alcohol-induced changes in driving behavior should be manifest in some fashion; accordingly, they should be amenable to systematic observation and recording. However, no empirical data are available to provide direct support for this assumption or for the inferential leap from post hoc epidemiologic sleuthing and from precise experimentation under artificial conditions; that is, no controlled study has yet been conducted to obtain systematic but unobtrusive data on the actual influences of alcohol upon real-world driving behavior in its natural environment. The urgent need for this type of research has been discussed elsewhere (Perrine, 1973a, 1973b, 1974a).

In what amounts to a useful cross-fertilization, several behavioral factors have been suggested by epidemiologic research as having recurring patterns in crashes. For example, after reviewing a number of epidemiologic studies, Brown (1972) concluded that the driver is wholly or partially responsible for at least 85% of all traffic crashes, whereas the relevant contributions of the other two factors in the traffic system -- the vehicle, and the environment -- cause relatively few crashes (less than 5% each) when acting independently or in combination. Brown has estimated that about two-thirds of all crashes "can be shown to result from mismatches between the driver's decision-making behavior and the demands imposed on him by the traffic system (1972, p. 166)." Therefore, in terms of sheer magnitude and relative contribution to the general problem of crashes, psychological research on these mismatches would seem to provide the greatest potential source for remedial measures in crash reduction and prevention. Accordingly, this review is limited to the overwhelmingly most important factor in the pre-crash phase: the human operator. Research on the contributions of the other two factors (i.e., the vehicle and the environment) to alcohol-involved crashes has recently been reviewed by Voas (1973a). Furthermore, the present review is limited to the experimental literature; for epidemiologic evidence of alcohol involvement in highway crashes, the reader is referred to several recent examinations (Perrine, 1974a, 1974d; Zylman, 1974).

In analyzing the behavioral aspects of the pre-crash phase more specifically, one could say that the driver did not anticipate the mismatch (or the occurrence of the crash) and/or was not ready to take corrective action, thereby implying that in oversimplified terms, he: (1) was not <u>attending</u> adequately, (2) was not <u>processing</u> relevant information adequately, and/or (3) was not <u>responding</u> adequately. Of these three general levels of functioning, the attentional-perceptual is probably the most important since in a potential crash situation, the initial registration of relevant stimuli -- mediated by attending -- is a crucial pre-condition for both the other levels of functioning (i.e., for subsequent information processing in terms of selecting both perceptual interpretations and responses, and for actual response execution). Epidemiologic evidence for this assumption is provided by a study of road-user errors for which data were obtained from on-site investigations of crashes and from follow-up interviews (Clayton, 1972). Excluding errors classified as having been due to excessive speed, almost half the errors were attributed to the perceptual-attentional level, namely, "failure to look" and "misperception" (Clayton, 1972, p. 71).

Thus, if alcohol is involved in half the fatal crashes, if at least two-thirds of crashes result from a mismatch between the demands of the traffic system and the driver's decision-making capacity at the moment, and if half the crashes involve attentional-perceptual errors, then a combination of these factors is doubtless involved in a very significant proportion of the crash problems -- and thereby represents enormous potential for possible countermeasures. The interrelations among these factors raise a number of compelling questions for investigation, as well as a series of urgent challenges for countermeasure development.

At the level of analysis represented by the present review, however, the major question arising from the above analysis is: "If alcohol contributes to *this mismatch*, to what extent does it do so, and how?" Increasing evidence has been mustered in recent years to indicate that alcohol can contribute significantly to the mismatch, primarily through its influences upon attention in particular, and upon information processing in general. However, the extent depends upon many factors, one of the most important being the relative amount of alcohol involved. Accordingly, in the present review, greatest emphasis has been allocated to experiments concerned with those aspects of behavior which have been most highly implicated in highway crashes: attentional-perceptual and other information processing aspects. In this context, it is noteworthy that in their analysis of the literature concerning laboratory experiments on alcohol effects upon human performance, Levine et al. (1973) found that perceptual-sensory tasks -- especially selective attention -- appeared to be most impaired by alcohol.

INFORMATION PROCESSING

The term "information processing" has a wide band of usage, ranging from a technically very specific information-theoretic meaning to a general label for "perception-attention-cognition-response selection" (but usually not including response implementation). However, discussion of these definitions and their semantic nuances is beyond the scope of the present review. As used here, "information processing" is simply meant to serve as a rather general organizing category to include studies which could also be specifically identified by such key words as: intensive, selective, and divided attention; pattern recognition; and certain aspects of short-term memory and choice reaction time. One special case is a performance task known by the trade name of its instrument, namely, the Phystester. As a matter of organizational convenience, studies which used part-task simulators are treated separately in the next section, even though attentional and information processing tasks were involved.

THE NATURE AND LOCUS OF ALCOHOL EFFECTS

In addition to determining its nature, one of the most important and most challenging questions concerns the exact locus of alcohol impairment on information processing. It is not yet clear just what alcohol is impairing in these functions and at what level. Much of this problem is due to a combination of the following factors: (1) the traditional intrinsic difficulty in separating influences upon perception, attention, and cognition from influences upon responses (a problem which is compounded in experiments using alcohol or other drugs); and (2) the relative absence of programatic series of systematic model-testing experiments. Nevertheless, some progress is being made in the alcohol problem areas, notably in a series of studies by Moskowitz and his associates (Burns, 1972; Moskowitz, 1973a, 1973b, 1974; Moskowitz & Burns, 1973) and by Huntley (1972, 1973c).

In almost all these experiments (and their related predecessors), response latency was taken as the primary indicator of information processing; and various strategies and models were then invoked in the attempts to attribute changes in reaction time to alcohol influences upon implicated aspects of the information processing sequence. On the basis of his review, Moskowitz (1973b, 1974) found "unanimous agreement that alcohol causes greater response impairment when the response requires complex information processing than when only simple motor reaction times are involved." He also concluded that his "brief review suggests that the site of the alcohol impairment of division of attention is most likely an impairment of the rate of information processing, with some secondary evidence to suggest involvement of the attention switching mechanism per se."

In an attempt to determine whether the alcohol-induced decrement in complex information processing is related to the amount of information, Moskowitz and Burns (1973) used overlearned, highly compatible stimulus-response combinations in which the subjects were required to name briefly displayed one- and two-digit numbers. Response latencies in naming the numbers were obtained from 20 male subjects, each of whom was tested on each of six different stimulus-set conditions. That is, the size of the stimulus set in each condition ranged from 1 to 32 different possible numbers which could be presented during a condition. These differences in stimulus uncertainty (i.e., the number of stimulus possibilities) were assumed to be an indicator of the amount of information to be processed. Since the required response of simply naming the displayed number is overlearned and is extremely compatible with the stimulus, few conflicts would be expected in selecting the response itself, i.e., S-R association strength is very high and, therefore, response competition and indecision should be very low. On two different days, each subject drank a combination of vodka and orange juice calculated to produce target BACs of 0 and 80 mg/100 ml (with an obtained mean BAC of 65 mg/100 ml).

Moskowitz and Burns (1973) found that for both the alcohol and the control conditions, response latencies increased significantly as the number of stimulus possibilities increased (from 1 through 32, or from 0 through 5 bits of uncertainty, respectively). They also found that the response latencies were significantly longer in the alcohol than in the control treatment. However, the magnitude of the alcohol effect was essentially constant across all stimulus-response uncertainty conditions (i.e., 2 through 32 stimulus-response possibilities, or 1 through 5 bits of uncertainty, respectively). It should be noted that the reported increase in response latency for the two most complex conditions (16 and 32 stimulus-response possibilities, or 4 and 5 bits of uncertainty, respectively) may well have been an artifact of the investigators' use of two-digit stimuli in these conditions, as opposed to the exclusive use of one-digit stimuli in the other, less complex conditions. Moskowitz and Burns (1973) concluded that "alcohol impairment appears not to be a function of amount of information." They also concluded that "some other dimension of information processing relates alcohol susceptibility and task complexity or information load (Moskowitz & Burns, 1973, p. 839)."

The Moskowitz and Burns (1973) study may be valuable in showing that on an overlearned task, alcohol does not impair information processing time differentially as a function of increases in the size of the stimulus set. However, another interpretation of these results would increase their generalizability to other studies and principles. Thus, it is highly probable that no alcohol-induced increase in response latency was obtained (as the size of the stimulus set increased from 2 to 32) precisely because the response compatibility was so high; and this factor is independent of increases in the size of the stimulus set (Smith, 1968, p. 84). In other words, since the S-R association strength was high and the responses were highly familiar (or "overlearned"), Moskowitz and Burns were not really testing alcohol influences upon information processing time by varying "task complexity or information load;" rather they were simply manipulating the size of the stimulus set. Furthermore, it is probable that if in the control treatment, the condition involving stimulus uncertainty of zero (i.e., only one possible stimulus) were excluded and if the stimuli in all conditions had the same number of digits (e.g., two), then the statistical significance of this main finding would disappear. That is, the numeral-naming response latencies would not increase as a function of increased size of stimulus set, which would be consistent with other studies (e.g., Garner, 1962; Hawkins & Underhill, 1971; Smith, 1968). Therefore, their design and task provide no differential data concerning the output side of the information processing sequence in terms of cognitive response selection or response execution. In terms of this interpretation, then, their results are quite understandable and are consistent with those of other studies which have shown that reaction times are quite resistant to alcohol impairment in tasks requiring responses which are relatively simple, compatible, and highly familiar (for example, in the Huntley studies reviewed below).

In a doctoral dissertation concerned with alcohol influences upon divided attention from an information-theoretic approach, Burns (1972) attempted to test information processing limits with three levels of information load, two levels of BAC, and two very broad levels of age (but no aspects of the latter variable are relevant for present purposes and are not considered). Using a meticulously developed light and/or tone discrimination task, Burns (1972) manipulated "effective information load" by varying the number of possible stimuli in a given condition, namely, 2, 3, or 4 discriminably different intensities of very briefly presented light and/or tone. The subjects were required to associate a numeric response to identify a particular light or tone: 1, 2, 3, or 4 were associated in serial order with the descending intensities of either the light series or the tone series. Burns treated the discrimination learning trials (when either a single sound or a single light occurred on each trial) as the "concentrated attention component" of the experiment, and interpreted the number of trials required to reach criterion as measuring the effect of information load on this task. Since no alcohol treatment was used with these learning trials (the "concentrated attention task"), Burns was only able to examine the influence of the number of possible stimulus-response alternatives on the number of trials to criterion; she found that the latter increased significantly with increases in the former. She concluded that performance of a concentrated attention discrimination task is a function of the effective information load, "defined as number of possible alternatives."

Once having reached the required criterion (90% or more correct) to separate presentation of the signals on the discrimination learning component of the experiment, the subjects received the divided attention discrimination task which consisted of simultaneous presentation of a single tone and a single light. Three levels of effective information load were used in which either 2, 3, or 4 possible light/tone combinations were involved, thereby yielding 4, 9, or 16 possible combinations. In a counterbalanced design, each of 12 subjects drank a combination of vodka and orange juice calculated to produce target BACs of 0 and 80 mg/100 ml (with an obtained mean of 70 mg/100 ml).

Burns (1972) found that as the number of stimulus-response possibilities increased, the percent correct responses decreased and the amount of information transmitted increased. In terms of the extensive evidence for its relevance and sensitivity in such tasks, it is surprising that reaction time was not included as a dependent variable. Burns concluded that "performance in a divided attention, bimodality discrimination task is a function of the effective information load." However, the alcohol-induced decrements in performance were essentially constant across the three levels of information load. That is, under alcohol, the subjects appeared to suffer no greater deficit when required to respond to 1 of 16 possible stimulus combinations, or 1 of 9, or 1 of 4. Accordingly, the alcohol-induced decrement in percent correct responses on the divided attention task did not increase as the effective information load increased. As in the Moskowitz and Burns (1973) study, it was concluded that "amount of information, as measured by number of possible stimulus alternatives, has no interactive relationship with alcohol effects (Burns, 1972, p. 97)." However, this conclusion is based on measures (percent correct responses, and bits of information transmitted) which are not time-bound and thus may not be as sensitive to alcohol influences in this type of divided attention task as a reaction time measure. As an alternative explanation, Burns suggests that "the number of processing steps required by the task is the variable which interacts with alcohol to produce performance decrements (1972, p. 97)," but she does not elaborate on this broad suggestion. However, Huntley (1973c) has recently demonstrated the probable validity of this suggestion; furthermore, he used a design and conceptual model which enabled him to reach much more specific conclusions.

Two related studies by Huntley (1972, 1973c) provide definitive data on several important questions concerning alcohol influences upon information processing. He was interested in determining whether alcohol influences the more central (cognitive) or the more peripheral (sensation and response execution) aspects of information processing, and whether the input or the output aspect of central processing is more susceptible to these influences.

In the first study, Huntley (1972) examined the general notion that alcohol influences increase as the complexity of information processing increases. To this end, he employed a more direct metric for information complexity (i.e., the *number* of stimulus-response possibilities) than had been used in previous alcohol studies. The subjects were trained to associate a (randomly assigned) single-digit number to identify each of the 8 cells of a small 4 by 2 matrix (i.e., it was calculated to fall within the limits of foveal vision). Their task consisted of saying the identification number of the cell in which a small dot was projected tachistoscopically. Choice reaction time was taken as the time from onset of stimulus presentation to verbalization of the numeric designation of the particular cell within the matrix in which the dot appeared. The subjects were specifically instructed and were also given warm-up trials for each of the three uncertainty conditions used so that they would be set to attend only to the 2, 4, or 8 cell locations involved in the particular subsession. Thus, the stimulus (a black dot) was constant across all trials, the response was a single-digit number associated with a particular cell, and the three levels of information complexity were determined by the number of possible cell locations (2, 4, or 8) and associated identification numbers which thereby specified the three levels of stimulus-response uncertainty employed in the experiment. In this well-designed, completely factorial experiment, the nine young male subjects each received, on three separate days, each of the three beverage treatments (a placebo of water with a small amount of bourbon floated on the surface, imported 6% beer, or ethanol and water) calculated on the basis of body weight to produce target BACs of 0 and 100 mg/100 ml (with obtained mean BACs of 80 mg/100 ml for beer and 89 mg/100 ml for ethanol).

Huntley (1972) found that reaction times were significantly lengthened by alcohol and by increases in stimulus-response uncertainty; in fact, a significant alcohol-by-uncertainty interaction was obtained indicating that alcohol influenced reaction time differentially for the three uncertainty conditions. It is especially noteworthy for the interpretation being offered in the present review that no differences in reaction time between the alcohol and placebo treatments were observed for the simplest (the two-option) stimulus-response condition. In other words, reaction time is very resistant to alcohol impairment when the stimulus-response options in the task are few, highly familiar ("overlearned"), and/or very compatible. This point was also made in the interpretation of the Moskowitz and Burns (1973) results cited above, and it should be further noted that they obtained no appreciable difference between the alcohol and control treatments in their condition which had the minimum number of stimulus-response options, namely, one (or zero bits of uncertainty). It is unfortunate in this sense that Huntley (1972) did not include a one-option condition to anchor this effect conclusively at the lower end of his response-option scale. Nevertheless, these results in combination with others have extremely important implications for alcohol influences upon driving behavior, as is discussed below.

It should be noted in passing that Huntley (1972) found no significant differences between the beer and the ethanol treatments, both of which had been incorporated in the study because it was part of a series concerned with differential ethanol influences as a function of beverages which differed in congener content.

In his second experiment, Huntley (1973c) attempted both to verify the main conceptual finding of his first study and to specify more precisely the locus of alcohol effects within the information processing sequence. With explicit reference to Smith's (1968) four-stage model of information processing, Huntley was interested in determining the differential alcohol sensitivity of the two traditional dichotomous aspects of processing: input (Stage 1: stimulus registration and detection; and Stage 2: stimulus recognition) and output (Stage 3: response selection; and Stage 4: peripheral response implementation). To enable differentiation between input and output, he separated stimulus effects from response effects by manipulating stimulus-response familiarity. More specifically, the stimulus was held constant, whereas the familiarity of the response was varied in two treatments: (1) complete familiarity, involving the straightforward verbalization of the single-letter stimulus as presented; and (2) relatively unfamiliarity, involving the verbalization of an associated single-digit number in response to the presentation of a particular single letter. Three levels of stimulus-response uncertainty were used, consisting of 2, 4, or 8 equally probable letters which were presented tachistoscopically in a modification of the apparatus used in his first experiment. The factorial design involved two groups of 12 subjects, each of whom was tested at the three levels of stimulus-response uncertainty at each of two target BACs (0 and 80 mg/100 ml) produced by an appropriate mixture of ethanol and orange juice calculated on the basis of body weight.

Huntley (1973c) found that reaction time was lengthened significantly by increases in stimulus-response uncertainty, and the magnitude of these increases was significantly greater when the associated novel responses were required. No significant alcohol effects were obtained with the completely familiar and congruent verbalizations of the stimulus letters themselves. However, when the associated numeric or novel responses were required, reaction time was significantly lengthened by alcohol and the magnitude of this effect was significantly enhanced by increasing stimulus-response uncertainty. Statistically significant differences were obtained in the analysis of the slopes, as well as the intercepts of the reaction time functions. On the basis of these results, plus the fact that the two tasks differed only in the relative familiarity of the required responses, Huntley concluded that the uncertainty effects occur primarily in the response aspects of processing and include both response selection and response implementation. Huntley believes that "when stimulus-response combinations are relatively novel, as in the unfamiliar condition, the stimuli elicit response conflict among the various response possibilities. This necessitates increased attention in selecting the correct response with a corresponding increase in RT and an increase in the magnitude of alcohol influences as well." Thus, it may be tentatively inferred that the major effect of alcohol occurs at Stage 3 of the four-stage model used by Huntley.

In summary, Huntley (1973c) concluded that "the locus of the alcohol effects in the information processing sequence appears to be in the stimulus-response translation process; i.e., in response encoding rather than with stimulus recognition per se or response execution." This conclusion is consistent with the interpretation that information processing is relatively resistant to alcohol impairment at medium BACs when both stimulus and response conditions are completely congruent or at least are highly familiar. By contrast, alcohol impairment of information processing increases as the required complexity of processing increases, whether in terms of an increase in: (1) possible locations of stimulus occurrence (as in Huntley, 1972), (2) the number of new associations required for successful task performance, or (3) the relative novelty of associations between input and output. It should also be noted that the results in Huntley's (1973c) familiar response condition are consistent with the Moskowitz and Burns (1973) finding of no alcohol effect as a function of the amount of information. Both sets of results are consistent with the interpretation offered above that in these types of tasks involving high stimulus-response association strength and requiring responses which are straightforward, compatible, and highly familiar, reaction times manifest relatively little alcohol impairment.

DIVIDED ATTENTION

One of the most important questions regarding information processing in the context of the present review concerns alcohol influences upon the allocation of attention and effort in situations which involve time sharing or dividing attention between two or more concurrent tasks (for recent reviews, see Huntley, 1973a, 1974; Moskowitz, 1973a, 1973b, 1974; Perrine, 1973b).[5] An interrelated series of divided attention experiments involving both central (foveal) and peripheral (extrafoveal) visual tasks has been conducted at the University of Vermont, both in the laboratory and in an instrumented car operated under relatively realistic nighttime driving conditions (Huntley, 1973a, 1973b; Huntley, Kirk, & Perrine, 1972; Huntley & Perrine, 1973; Perrine, 1973b).

The rationale for this series of divided attention studies derives from the fact that motorists and other individuals who have consumed abundant quantities of alcohol frequently report a reduced awareness of activity in the peripheral areas of the visual field. Similarly, peripheral sensitivity is reduced by the requirement to perform a second task concurrently, and the decreases in sensitivity become greater as the targets are displaced farther and farther from the center of the visual field, thus yielding what has been termed a "funnel effect" (Huntley & Perrine, 1973). This degrading influence of one concurrent task upon the performance of another is usually interpreted as supporting the notion that our time-sharing or attentional capacity is limited. Similarly, the influences of alcohol upon peripheral vision can be interpreted as being the result of a reduction of available attention.

The first experiment in this series was a doctoral dissertation (Huntley, 1973b) conducted to investigate the so-called "funnel vision effect" by examining the influences of alcohol and the difficulty of a concurrent foveal task upon responsiveness to light flashes presented to the dark-adapted eyes from five selected locations on the horizontal meridian of the extrafoveal field. Choice reaction time to these extrafoveal light flashes was measured in nine young adult males with normal vision. On three different days, each subject drank a combination of ethanol and orange juice calculated on the basis of his body weight to produce target BACs of 0, 50, and 100 mg/100 ml. Huntley (1973b) found that the mean choice reaction time to extrafoveal stimulation increased significantly in the two alcohol conditions and also increased significantly with increases in foveal task difficulty and target eccentricity. However, performance of the foveal task was not influenced by BAC. It was concluded that choice reaction time to extrafoveal stimulation was increased both by alcohol and by difficulty of the concurrent foveal task. When used in combination, these two stressors appear to operate independently, i.e., their influences upon choice reaction time are additive. No evidence was obtained in support of the so-called "funnel-vision" notion, i.e., that a progressive reduction in extrafoveal sensitivity with progressive increases in the eccentricity of retinal stimulation is caused either by alcohol or by the difficulty of the concomitant foveal task. In other words, each of these stressors causes an overall, homogeneous decrease in responsiveness to peripheral stimulation.

Perrine (1973b) has reported that two factors may have contributed to the lack of funnelling effects in the first experiment: (1) the peripheral stimuli may have emitted too much light, and (2) dark-adapted vision was used. Consequently, the study was replicated with a few specific modifications: (1) the subjects were not dark-adapted, and (2) a simple reaction task was used. The results approximated those of the first experiment very closely and, therefore, raised serious question about the validity of the "funnel-vision" notion. Furthermore, the results provided additional support for conceptualizing attention as being divided functionally in terms of relevant tasks, rather than in terms of some physiological continuum. Since simple reaction time was used in this second experiment, the influences of alcohol and subtask difficulty were shown not to be dependent upon the choice reaction time variable per se. Thus, it was concluded that alcohol reduces the ability to perform two or more tasks concurrently, and that the relative difficulty of a subtask influences the allocation of attention.

Perrine (1973b) also reported another variation of this study in which the probability of signal occurrence was varied for both a foveal and an extrafoveal location. Reaction times of 36 subjects were determined on each of three separate test days and at three target BACs (0, 25, and 110 mg/100 ml) while they concurrently performed on an auditory loading task for which two different levels of task difficulty were used. It was found that reaction times were affected by the probability of signal presentation. More specifically, reaction time to signals in the higher priority regions were shorter, regardless of the signal's spatial location. Of even greater interest, reaction times to the higher probability signals were significantly resistant to the effects of both alcohol and of foveal task difficulty.

On the basis of the laboratory experiments, the Vermont group decided to test the robustness of the divided attention results in a driving situation (Huntley, 1973a; Huntley, Kirk, & Perrine, 1972; Perrine, 1973b). They were also very interested in investigating the magnitude of alcohol increases in reaction time using a relatively realistic driving situation since the magnitudes of the increases obtained in the laboratory tasks were not very large proportionately (rarely exceeding 10%), even though they were statistically significant. Thus, they were interested in determining whether the influences of alcohol upon reaction time are large and reliable enough to be obtained in a real-world driving situation when the response to be measured is as gross and variable as depression of the brake pedal. The instrumented car was driven by two subjects over a 2.7-mile circuit of deserted road on each of eight experimental nights, after drinking a sham placebo or ethanol and orange juice beverage calculated to produce target BACs of 0 and 100 mg/100 ml, respectively. The primary task was to maintain a constant speed of either 15 or 25 miles per hour, whereas the subtask required the subject to depress the brake pedal as soon as possible after detecting one of three small lights mounted on a horizontal perimeter located slightly above his head inside the car.

It was found that alcohol caused increases in the reaction time to the light signals as well as increases in foot- and hand-control use, heart rate, and heart-rate variability. Driving also increased reaction times to the light signals, and heart-rate variability was increased by signal presentation. Driving speed influenced driving behavior differently than alcohol and was associated with a reduction in steering wheel reversal. It was concluded that BACs slightly above the threshhold for legal impairment (the mean BAC across all conditions was 116 mg/100 ml) alter the normal state of the central nervous system in a driving situation, decrease driving efficiency, and severely reduce performance on <u>detection</u> subtasks which require gross motor responses.

The Vermont group conducted a second study with the instrumented car to improve upon some of the limitations in the first study, as well as to increase the complexity of the design to investigate both simple and choice reaction time (Perrine, 1973b). Each of four subjects was individually tested on each of seven separate nights at the same time each night. The ethanol and orange juice beverages were calculated to produce target BACs of 0, 60, and 120 mg/100 ml. The subjects were specifically instructed that the main task was to keep the car located over a 3" white line painted along the middle of the road. In order to emphasize the importance of the tracking task, the subjects received a monetary reward for the total time that the car was "on target" during each trial. Tracking performance was monitored by a photo-sensor mounted underneath the car and connected to a "feedback light" and timer located in the car. Drivers were also instructed to maintain a constant speed of 12.5 miles per hour. The secondary task required the subject to monitor the perimeter in front of and slightly above his head for onset of one of two light-emitting diodes mounted 80^{o} left and right of center. In the simple reaction time condition, the subject was to respond consistently within that particular treatment according to a predetermined instruction (either to steer left, steer right, accelerate, or brake). In the choice reaction time task, however, the subject was required to respond differentially to the particular letter that was displayed each time on the light-emitting diode (M, D, H, and T), each of which had been associated with a particular response (i.e., a brake depression, an accelerator reversal, or a 20^{o} steering wheel movement to the left or to the right, respectively).

Analysis of the data from this second car study indicated that alcohol significantly increased both simple and choice reaction time. Alcohol also significantly increased coarse steering reversals in both simple and choice reaction time treatments, whereas it significantly decreased the time-on-target in both simple and choice reaction time treatments. It was concluded that both the medium and high BACs substantially reduced driving efficiency and severely reduced performance on a recognition subtask which required a choice between four mutually exclusive gross motor responses. Thus, alcohol impaired allocation of attention on both a recognition subtask (choice reaction time task in the second car experiment) and detection subtasks (simple reaction time tasks in both car experiments).

In summary, this series of studies provides further evidence that alcohol interferes significantly with the allocation of attention (or time-sharing) in both driving and driving-related situations in which performance on central visual tasks is pitted against performance on peripheral visual tasks. These results are in general agreement with related research cited in recent reviews (Huntley, 1973a, 1974; Moskowitz, 1973a, 1973b, 1974; Perrine, 1973a, 1973b, 1974e; Wallgren & Barry, 1970). However, the particular strength of these studies lies in their being able to relate the results from repeated-measure factorial experiments conducted under laboratory conditions to repeated-measure factorial experiments conducted in an instrumented car driven on closed courses. These investigators have thereby been able to relate and test laboratory results in driving situations which approximate real-world driving much more than has been accomplished through the use of part-task simulators.

It should be noted that interrelated studies conducted both in the laboratory and in simulators should nevertheless be encouraged, primarily because the experimental environment can be more carefully controlled in simulator research than in instrumented car research. It would clearly be desirable to conduct an interrelated series of experiments at all three levels. However, the most important level of research -- and actually the ultimate level in terms of validity -- remains the real world, with unobtrusive measures obtained under naturalistic conditions. Unfortunately, no published investigations of alcohol influences upon driving have been conducted under such circumstances, although an on-going study which apparently meets these criteria was mentioned by Perrine (1973b), but results were not yet available.

OTHER STUDIES USING ATTENTION

Several studies should be briefly mentioned which included various attention tasks in order to obtain response measures on some dependent variable, but which were primarily designed to investigate other aspects of alcohol influences (such as fatigue or adaptation). For example, a well controlled experiment by Staak, Springer, and Schoor (1972) was primarily concerned with a thorough examination of the influences of low BACs (less than 50 mg/100 ml) upon a variety of "psycho-diagnostic" laboratory tasks. These investigators felt that the literature was cluttered with conflicting results of such performance at low BACs and were determined to examine a wide variety of tasks under carefully controlled double-blind conditions. The three tasks of particular relevance for present purposes were: an attentional loading test which involved cancelling specified letters in lines of text; selective attention as measured by the Vienna Determination Apparatus; and tachistoscopic identification of traffic signs and signals. The other tasks involved tapping, critical flicker frequency, optical and visual reaction time, visual-motor coordination, and problem solving using arithmetic calculations. In a related report, the investigators also examined the influences of low BACs upon mood and upon semantic differential performance (Staak, Springer, & Schoor, 1973). None of the data from the 15 subjects on all these tasks showed any statistically significant differences even though the investigators did a saturation analysis using t-tests and Wilcoxon tests on all major combinations, an approach which increases the likelihood of finding significant values even though some would be spurious. In other words, low BACs were not significantly associated with negative influence on any of these laboratory tasks, including several varieties of attention. These results are welcome, coming as they do from a single well-designed study using double-blind conditions, but they are certainly not surprising. Rather, they are consistent with the literature examined in several recent reviews (Barry, 1973, 1974; Moskowitz, 1973b, 1974; Perrine, 1973a, 1974e; Wallgren & Barry, 1970).

THE PHYSTESTER: AN INFORMATION-PROCESSING INTERLOCK DEVICE

A number of firms, institutions, and governmental agencies have attempted to develop ignition interlock devices which would prevent alcohol-impaired individuals from being able to start a car which was so equipped. One of the most highly developed and widely circulated was the General Motors device called the Phystester. (A more promising second-generation approach to this problem, called the Critical Tracking Task, has been developed recently at General Motors and is reviewed below.) It should be very clearly noted at the outset that the Phystester studies are included in the present review primarily because of the popular impact and wide interest generated by the device rather than because of its probable utility or the scientific merit of the experimental results published to date (Jones & Tennant, 1973; McDowell & Smith, 1973; Sugarman, Cozad, & Zavala, 1973).

The Phystester itself is very similar in appearance to the small, hand-held calculators with 10 single-digit keys (although the configuration of keys on the Phystester is curiously just the opposite of that used on all such calculators and adding machines) and has a lighted multi-digit visual display. The behavioral components of the Phystester consist of a primary task, which involves short-term memory and a certain degree of psychomotor keyboard skill, and a secondary task, which is based upon the divided attention paradigm. In operation, a 4- or 5-digit number is briefly presented on the visual display and the subject is then required to enter the number accurately and quickly on the keyboard within a restricted allowable response time. At some random point within this time period, a light suddenly appears on the display which signals the operator to interrupt the keyboard task and quickly press a specified button before returning to and completing the primary task.

Jones and Tennant (1973) have summarized three studies involving the Phystester; however, for only two of these studies did they present enough marginally adequate alcohol information to begin to permit meaningful evaluation. The first was conducted by Systems Technology, Inc. and is unpublished; the other by Sugarman et al. (1973) is reviewed below. Apparently two series of alcohol experiments were conducted in the first investigation by STI using a heterogeneous group of 54 subjects dosed with vodka and an ad lib mix on the basis of body weight to an obtained mean BAC of 130 mg/100 ml. In lieu of any group data or statistical tests, Jones and Tennant present two graphs representing the data of two individual subjects to "illustrate typical results" for the "open-ended" time experiments, and one graph representing the individually plotted data of 22 subjects (7 of whom "got sick but completed all data") as "an illustrative sample of the alcohol effects observed for the 'fixed' time experiments." In the authors' words, "both experiments indicated very nonlinear effects of alcohol on performance...(and) even when marked degradations in performance are observed, they take place over a wide range of BAC's, suggesting that no fixed value of BAC could be chosen as a threshhold for acceptable performance for a wide cross section of the driving population (Jones & Tennant, 1973, pp. 7-8)."

Regarding the second investigation (also reported by Sugarman et al., 1973), Jones and Tennant (1973) provide very little procedural information, other than that a heterogeneous group of 159 subjects dosed as above on the basis of either 1.5 ml or 1.75 ml of 100-proof vodka per pound of body weight to achieve an obtained mean BAC of 130 mg/100 ml, and that they were tested on a driving simulator task as well as on the Phystester. The authors present a correlation matrix showing many significant positive correlations for both Phystester and driving simulator performances with BAC. However, with the large numbers involved, a correlation as low as 0.134 is significant at the 0.05 level; and it should be noted (but was not) that correlational values this small account for only a minute proportion of the variance, namely, 1.7%. In fact, of the 27 significant correlations (out of a total of 30), 15 of them account for less than 6% of the variance and only 1 accounts for more than 22%. At these levels, there should be serious question concerning the possible utility of the Phystester and these measures for real-world application. In fact, regarding the outcome of this second study, Jones and Tennant have stated that "while the Phystester is capable of discriminating between sober and intoxicated individuals, the debilitating effects of alcohol are not large enough to eliminate more than 50 percent of the drivers at BAC's of 0.1 percent without eliminating also a large number of sober drivers (1973, p. 12)."

In conclusion, the authors noted that programs were under way at General Motors to develop adaptive techniques (discussed below) for measuring performance under alcohol as a basis for an improved ignition interlock system. On the basis of the Phystester studies as summarized by Jones and Tennant (1973), it is certainly understandable that some other approach to the problem is being sought.

DRIVING SIMULATORS

One subdivision of the laboratory approach to studying alcohol effects upon driving-related behavior involves the use of part-task driving simulators. Although the devices used vary greatly in degree of sophistication and degree of simulation, they all have in common the utilization of one or more tasks which bear an explicit assumed relation to tasks actually involved in highway driving performance. Detailed consideration of these various devices is far beyond the scope of the present review; however, several surveys are available (Heimstra & Struckman, 1972; Hoyos, 1969; Hulbert & Wojcik, 1972; Waller, 1973).

A relatively large number of alcohol experiments utilizing driving simulators was located during the present review period, but only a minority of these used alcohol treatments alone and thereby met the criteria for inclusion in the present review. That is, a number of valuable simulator studies were published during 1972-1973, but were concerned with influences of various drugs, administered alone and in combination with alcohol. Unfortunately, none of these multiple drug studies provided unequivocal insight into alcohol effects because none had the necessary unconfounded treatment consisting of alcohol alone. In other words, all these studies used alcohol in combination with a placebo drug treatment, as well as in combination with the particular drug under examination. Therefore, none of these multiple drug studies is included in this review, but some of the more valuable ones are cited below for the convenience of the interested reader.[6]

The other driving simulator studies which used separate alcohol treatments can be categorized in terms of two different sets of interest: adaptive assessment techniques, and the time course of alcohol influences upon performance. Accordingly, the remaining studies are grouped and discussed below under these two headings. However, to provide a meaningful background for this discussion, a brief survey of previous findings is presented first since the only review of this literature (Heimstra & Struckman, 1972) is unfortunately not very readily available.

BACKGROUND

An excellent review of the pre-1972 literature concerning alcohol effects upon performance in driving simulators has been written by Heimstra and Struckman (1972). Beginning with the first study published in 1942, they were able to find only 14 studies (and only 12 of those were available for review) in which "the subpart of the driving task studied was investigated in a simulation of the driving situation." It is perhaps indicative of the increased research activity in this area that in the relatively brief time period since their review, 6 relevant studies have been found, 5 of which are discussed below. It should be noted that in the intervening time since Heimstra and Struckman labeled the UCLA simulator (Hulbert & Wojcik, 1972) as being "probably the most sophisticated device of its type currently in operation," an unequivocal contender for this title has appeared and has been used in one highly publicized alcohol experiment (Lewrenz, Berghaus, & Dotzauer, 1974), which was published too late for inclusion in the present review, however.

The two general classes of behaviors examined in the relevant driving simulator studies were motor performance and behavior involving higher mental functions according to Heimstra and Struckman. They ranked the six types of motor performance measures in descending order of frequency used in the 12 studies: tracking, steering inputs, accelerator inputs, speed, brake inputs, and signaling errors. They also categorized two basic forms of behavioral measures utilizing higher mental processes: simple reaction tasks and choice reaction tasks of varying degrees of complexity. These observations were also found to obtain generally for the simulator studies reviewed below.

Regarding the effect of alcohol upon behaviors measured in driving simulators, Heimstra and Struckman (1972) concluded that it was primarily associated with variability of performance, both within and between studies. They found no behavior on which completely consistent effects of alcohol had been reported more than once. Indeed, in many cases, alcohol appeared to have had opposite effects on the same behavior in different studies. Nevertheless, the authors concluded that the performance changes on tasks involving complex reaction time appear to have been more consistent than the changes in motor performance. In fact, this relative consistency -- along with the indication of the importance of complex, higher level tasks in some of the studies -- led to the conclusion that "perhaps the most important factor determining the impairment of the driving task is the effect of alcohol on the higher mental processes (Heimstra & Struckman, 1972, p. 27)."

In this regard, it is especially noteworthy that the authors found a majority of the experiments reviewed had only investigated behaviors relating to the "physical response output task." This is the fourth and final stage in the information-processing model mentioned above (Huntley, 1973c). It also represents the final component of Ellingstad's (1970) analysis of the total driving task into four subtasks: a search-and-scan task, a perceptual task, a decision function/cognitive response task, and a physical response output task. For at least two reasons, this finding more than any other single factor probably accounts for the general absence of any consistent alcohol impairment on the behaviors studied with driving simulators. First, according to the review by Levine et al. (1973), psychomotor tasks appear to suffer the least alcohol impairment, by comparison with cognitive tasks and perceptual-sensory tasks (which appeared to be most impaired). Secondly, according to Huntley's (1973c) investigation, alcohol effects upon the information-processing sequence do not appear to be localized at the response execution stage (or the stimulus recognition stage), but rather at the response encoding stage. Thus, in conjunction with the interpretations offered above, these two sources of evidence can account for the results upon which Heimstra and Struckman based their conclusions. The next question is whether the six studies published since their 1972 reveiw provide any reason for modifying these conclusions.

ADAPTIVE ASSESSMENT TECHNIQUES

One of the most promising recent developments in alcohol research is the attempt to utilize adaptive assessment techniques in this field. Two such studies have been presented (Strasser, Brilling, Klinger, & Müller-Limmroth, 1973; Tennant & Thompson, 1973) and others are known to be under way.

An innovative approach to measuring human performance has recently been developed by human factors specialists out of a necessity to assess behavior change efficiently in situations involving interactions among many variables. Under the general name of "adaptive assessment techniques," this approach was developed primarily for research in engineering psychology to measure the task-load reductions necessary to maintain performance at some specified level as stressor variables were increased (see special issue of Human Factors, 1969, II/6). In this approach, task difficulty is automatically adjusted to maintain performance at criterion level. Accordingly, as performance improves, the task is made more difficult, and as performance worsens, the task is made easier -- thereby essentially holding performance constant and establishing task variables as measures of change. To date, this approach has been used primarily to assess training; however, it has applicability for quantifying the effects of stressor variables in a task that is well learned. In fact, the technique is apparently versatile enough to be used in tasks ranging from tracking to time-estimation measures.

In an attempt to devise a valid alcohol-interlock system for eventual installation in cars (analogous in purpose to the Phystester discussed above), researchers at General Motors have turned to adaptive assessment techniques (Tennant, 1973; Tennant & Thompson, 1973). They have labeled their version "The Critical Tracking Task" (CTT), which is a compensatory tracking task that uses an oscilliscope for the display and an isometric force stick for the control manipulator. The authors hypothesized that the maximum degree of task difficulty which could be handled without error would discriminate those subjects with high BACs from those with low or no BAC.

Subjects were trained until their performance asymptoted on the tracking task which increased in difficulty (or "instability") within each trial as a function of time and which terminated upon failure. In a second session two weeks later, subjects were given 20 practice trials prior to ingesting 4 paced drinks during the subsequent 80-minute period. Then, after a 40-minute wait, the subjects were given 10 test trials on the tracking task, at which point the authors assumed (incorrectly) that the subjects would be "at peak BAC."

Each of the 76 subjects (47 males and 29 females, ranging in age from 19 to 65) drank a combination of 100-proof vodka and either orange or tomato juice, determined on the basis of the subject's body weight and reported drinking habits (i.e., so-called very light drinkers, occasional drinkers, average drinkers, and above-average drinkers were administered 1.00, 1.25, 1.50, and 1.75 ml/lb body weight, respectively). However, unspecified deviations from these dosage procedures were mentioned; "during the drinking period, changes were occasionally made in the amount of vodka given per subject, based upon visual evidence of intoxication or lack of it and on verbal reports of nausea (Tennant & Thompson, 1973, p. 5)." The mean BAC was 110 mg/100 ml, with a range from 56 to 190 mg/100 ml (apparently not including data from the 7 subjects who became ill). Given this extremely wide range of BACs, Tennant and

Thompson attempted to avail themselves of what appeared to be "an opportunity to examine the degree of deterioration on the task as a function of the various BAC levels." For the purpose of this analysis, the subjects were assigned post hoc on the basis of achieved BAC to one of five groups which consisted of very unequal class intervals of the BAC distribution from 50 to 200 mg/100 ml (i.e., their five groups had class intervals of 30, 18, 19, 29, and 50 mg/100 ml, respectively.

Regarding "sober versus intoxicated performance," Tennant and Thompson (1973) used t-tests in an attempt to analyze differences in before-and-after alcohol scores. They found significant ($p<.05$) decreases in CTT scores in each of the five post hoc BAC groups when the final five training trials were compared with the first five alcohol trials. Unfortunately, the authors did not state whether the final five alcohol trials differed significantly from the first five, or for that matter, from the last five training trials.

Regarding threshold CTT scores that might be applied for interlock purposes (i.e., cutting scores), Tennant and Thompson (1973) stated that for BACs of 100 and 140 mg/100 ml, failure rates of 50% and 75%, respectively, can be achieved with a sober failure rate of 0. In other words, 50% and 25% false negatives at BACs of 100 and 140 mg/100 ml, respectively, but no false positives. However, these statements are based upon two tables which are extremely difficult to interpret, primarily because very little procedural information is given concerning the circumstances under which the data were obtained. For example, the number of subjects reported for each BAC column in these two tables does not correspond to any values given either in the text or in the tables themselves. Thus, one is left with the impression that some performance data were obtained from subjects who only served in a no-alcohol condition, whereas other data were obtained from subjects who served in both an alcohol and a no-alcohol condition.

As interesting as the general conclusions from this study may be, it suffers from a number of very serious methodological problems which severely limit interpretation and generalization. For example, the treatment conditions were not counterbalanced; that is, the order in which the training trials and the alcohol trials were received was the same for all subjects, such that the alcohol condition always followed the no-alcohol condition which introduces the strong possibility of confounding order effects. Furthermore, no control groups were used, that is, a group which received no beverage whatsoever and/or a group which received a placebo or sham drink. Finally, BAC was completely confounded with reported drinking experience since the latter was used as the basis for differential dosage, yet subjects were then assigned to "independent" analysis groups on the basis of achieved BACs. Despite the methodological limitations, the results from this study imply that the adaptive assessment technique is sufficiently sensitive to alcohol impairment to warrant further investigation under rigorous experimental conditions.

As a secondary part of an investigation of tracking performance with both fixed and adaptive self-adjusting degrees of difficulty, researchers at the Munich Technical University's Institute for Physiology of Effort also examined influences of alcohol upon such performance (Strasser, Brilling, Klinger, & Müller-Limmroth, 1973). Nine experienced jet pilots served as subjects who performed on a sophisticated pursuit tracking test with four different forcing functions, two of which furnished a tracking task with a more or less constant degree of difficulty, whereas the other two continually changed in their degree of difficulty, depending upon the performance of the subject. On the basis of a dosage technique which is apparently quite popular among German investigators in legal medicine, the subjects reached a mean BAC of 60 mg/100 ml after partaking of a "Sturztrunk" (which could be translated as a tossed, gulped, or "waterfall" draught), that is, by consuming the entire dose without pausing. The investigators did not find significant alcohol impairment of tracking performance, but this may have been due to the combined factors of the high skill level of these specially selected subjects and the unfortunate confounding of learning effects and alcohol effects. However, the authors did report a disproportionate decrease in the amplitude of acoustically evoked potentials under alcohol which they interpreted as a reduction in vigilance. Thus, for present purposes, the results of this pilot study can only be regarded as having potential heuristic value for more rigorous, counterbalanced experiments in the future.

TIME AND ALCOHOL EFFECTS UPON DRIVING SIMULATOR PERFORMANCE

The second category of phenomena in which driving simulator researchers have been interested can be characterized in terms of elapsed time, that is, possible differences in alcohol influences upon performance simply as a function of the time course involved in the absorption and elimination of alcohol. Hurst and Bagley (1972) have recently presented an excellent review of the literature concerning one of the most important -- and certainly one of the most controversial -- issues in this area, namely, comparisons of behavioral effects at equivalent BACs during the absorption phase and during the elimination phase, typically considered under such rubrics as "acute adaptation" or "the Mellanby effect." (The non-simulator studies concerned with this effect are considered separately in the next section.) It should be noted that the German literature is heavily weighted with a preponderence of studies concerning alcohol metabolism and the time course of alcohol influences upon behavior, apparently due to the legal-medical aspects of their "drunken" driving laws which emphasize and frequently necessitate the retrogressive estimation of BAC at the time of a crash. Thus, it is not surprising that most of the studies in this second category were conducted in Germany and involve target BACs of 80 mg/100 ml. The necessity of obtaining performance measures over prolonged periods, coupled with the desirability of obtaining continuous measures, was doubtless involved in the choice of tracking tasks which simulated certain dynamic aspects of driving for these investigations.

Another study conducted at the Munich Technical University by two of the same investigators cited for the last study above (Strasser, 1972; Klinger & Strasser, 1972) used a pursuit tracking task as a basis for obtaining "objective" information concerning the time course of early alcohol effects with the critical BAC value of 80 mg/100 ml. In the first publication, Strasser (1972) reports procedural details and the results of the psychomotor tracking task during absorption and plateau phases of the blood alcohol curve. The task involved point-source pursuit tracking, using a steering wheel. A tone was used to provide auditory feedback to the subject when he exceeded a specified error tolerance. This signal was used as the stimulus for the auditory evoked potentials which were recorded for each subject, in addition to heart rate. Nine young male subjects received sufficient training on the pursuit tracking for their performance to have asymptoted before proceeding with the test session which lasted two hours. The Sturztrunk technique was again used with the requirement that the subjects consume a sufficient amount of 44% Slivowitz within five minutes to attain the target BAC, as determined by the Widmark formula. Despite the enormous emphasis in this study on alcohol absorption and elimination, etc., it is especially curious that no BAC data were presented, not even the mean BAC achieved by the subjects.

Regarding the pursuit tracking variables, Strasser (1972) reported observable, but statistically nonsignificant (and therefore negligible for all practical purposes) alcohol influences during the 15 minutes after the very rapid consumption of the test beverage. However, during the steepest and most rapidly accelerating portion of the absorption phase, a highly significant ($p<.005$) impairment of tracking performance was obtained, such that one hour after drinking, the accelerating tracking error was slightly higher than 40% and continued at this level during the plateau phase of the blood alcohol curve. Strasser concluded that alcohol impairment of performance trails the blood alcohol curve, with a lag from 15 to 30 minutes. He discussed the implications of this conclusion for the problems involved in attempting retrogressive calculation of the exact BAC at the time of an event such as a crash.

The physiological results from this study were reported separately (Klinger & Strasser, 1972). Regarding acoustically evoked potentials, a statistically significant damping or impairment was already manifest in the first data collection point at 10 to 20 minutes after consumption of the Sturztrunk. This depression continued throughout the observation time of approximately 60 minutes, at which point a tendency to return to the baseline and the adaptation level was observed. The authors concluded that after rapid consumption of alcohol, the effects are manifest much sooner on such central nervous system activities as evoked potentials than on such behaviors as psychomotor performance. They suggested that the actual BAC is not as decisive in this damping effect as is the rate at which BAC is increasing after the Sturztrunk. It was also suggested that the net effect of such alcohol impairment of evoked potentials can be conceptualized as a general fatiguing of the information processing capacity, and could perhaps be expressed as a reduction in "vigilance."

Regarding cardiac function, the heart-rate data showed a continually depressant and tranquilizing effect of alcohol which was already manifest five minutes following consumption of the Sturztrunk and continued throughout the one-hour observation period. However, a concurrent increase in heart-rate variability was observed and was interpreted as reflecting disruptive effects of alcohol upon physiological parameters. The authors concluded that the recorded changes over time support the view that alcohol effects upon physiological parameters do not parallel the blood alcohol curve, but appear to be somewhat more disturbing during the absorption phase. The obvious implications for highway safety were also discussed.

Heppner (1973) examined the time course of alcohol impairment on performance as measured in the driving simulator at the Technical University of Berlin. This simulator consists of a relatively complete model of a car and is instrumented to measure tracking errors, deviations, steering reversals, and speed. The 30 students who served as subjects received sufficient training on the simulator to reach asymptote. Each test session lasted 5 1/2 hours and consisted of 16 10-minute trials (5 sober trials followed by 11 alcohol trials). The course of the blood alcohol curve was determined on the basis of 10 blood samples taken every 20 minutes. In order to approximate real-world conditions as closely as possible, alcohol was administered in the form of 3.7% beer, with dosage of 1 g alcohol/kg body weight. The resulting blood alcohol curves were typically quite flat and plateau-like, and individuals with pronounced peaks were apparently quite rare. The mean BACs were 81, 97, and 87 mg/100 ml, respectively for the rising, maximum, and falling sections of the blood alcohol curve. However, Heppner obtained an extremely wide range of individual BACs, namely, 50 to 115 mg/100 ml.

Heppner (1973) found enormous individual differences in performance, probably due in large measure to the wide range of obtained BACs. The statistical analyses were not especially complex or powerful, but the general finding was an almost 4-fold (± 1.56) deterioration in performance under alcohol relative to sober performance. More specifically, and also relative to the sober baseline (13.7 errors), the average number of errors in the three sections of the blood alcohol curve were 45.7, 52.7, and 45.0, respectively in the rising, maximum, and falling sections. Thus, the mean errors of the rising and the falling sections of the curve were quite similar. However, the individual data show sufficiently wide differences to question the general effect of this type of beer dosage on the type of psychomotor performance examined in this experiment. For example, 11 subjects exhibited better performance on the rising than on the falling sections and, conversely, 11 other subjects exhibited worse performance on the rising than on the falling sections. Furthermore, in 6 cases, no difference in impairment was found between the rising and falling BACs. The author concluded that "thus, only a stochastic relationship obtains between the blood alcohol content and the deterioration in performance."

Finally, the driving simulator aspects of the study by Sugarman et al. (1973) should be mentioned briefly. The study was primarily concerned with an evaluation of the Phystester, was conducted under contract to General Motors, and was discussed above (as summarized by Jones and Tennant, 1973) in the subsection concerning the Phystester. The additional information of relevance for the present subsection concerns alcohol influences upon three measures obtained in the Cornell Aeronautical Laboratory Driving

Simulator: maintenance of lane position, maintenance of constant speed, and reaction time. The heterogenous group of 159 subjects received seven 5-minute cycles of simulator driving, spaced one hour apart for a total of six hours. The mean peak BAC was 122 mg/100 ml. Unfortunately, interpretation of the results is greatly limited by several problems: no control groups were used; no counterbalancing was used; the subjects had relatively little training on the simulator; and low powered statistical techniques were used to analyze the data (each subject's scores were transformed to z-scores, and then the results were simply correlated). Nevertheless, the general findings are consistent with those of other studies, namely, high BACs were associated with degradation of maintenance of lane position, reaction time, and speed maintenance. Furthermore, this impairment was more consistently observed during the absorption phase than at the same BACs during the elimination phase of the blood alcohol curve. Curiously, the authors state in conclusion that "the search for a task to be used as a countermeasure against the drinking driver shows promise. The lack of high correlations in our results, however, makes us join the ranks of those who ask if blood alcohol concentration is the best criterion for 'driving while intoxicated' (Sugarman et al. 1973, p. 5)."

In summary, all the above driving simulator studies have several methodological weaknesses in common. First, they did not employ counterbalancing or repeated measures, to say nothing of factorial designs. Secondly, however, they did not even use appropriate control groups. Thirdly, they all depended upon the assumption that the subjects had reached an asymptote of learning the tracking task, such that additional trials would have no increase in proficiency of performance. Accordingly, all these studies are limited to using relatively weak statistical procedures to analyze the data, with the concomitant danger that the use of many t-tests and correlations can lead to undetected spurious values of significance. Finally, the possible effects of learning, fatigue, adaptation, and alcohol are highly confounded in all these studies and thus set further limitations on the interpretation of the results.

In conclusion, the question posed at the end of the Background subsection should be re-examined: do the six studies published since the Heimstra and Struckman (1972) review provide any reason for modifying their conclusions? With one exception, this question can be answered quite clearly in the negative. That is, as in the pre-1972 literature, (1) psychomotor tracking was also the most frequently used performance measure in the studies reviewed above, and (2) the results were inconsistent and equivocal from study to study -- and in two cases, were equivocal within study. Nevertheless, these recent studies did provide additional evidence that alcohol was primarily associated with variability of performance, both within and between studies. Furthermore, these recent studies were similar to all previous studies in choice of dependent variables, namely, only behaviors relating to the "physical response output task" were investigated, with the exception of the physiological parameters of heart rate and auditory evoked potential recorded by Klinger and Strasser (1972). The one positive exception to the negative answer given above stems from the two attempts to utilize adaptive assessment techniques in alcohol research with driving simulators. Although the two studies reviewed (Strasser et al., 1973; Tennant & Thompson, 1973) both suffered from a number of very serious methodological problems, the results taken in combination do imply that the adaptive assessment technique may prove sufficiently sensitive to alcohol impairment to provide a very useful methodological tool for future investigations.

TIME PARAMETERS

In addition to the driving simulator studies reviewed in the previous subsection, a number of nonsimulator laboratory experiments has also been concerned with alcohol and time parameters. Most of these studies have focused on some aspect of "acute adaptation" (and two of these are reviewed below), but individual studies have been concerned with such variables as speed of alcohol ingestion (Jones & Vega, 1973) and length of testing time (Lewis, 1973). Compared with the dearth of studies investigating alcohol and time parameters prior to 1972 (as noted by Levine et al. 1973), the relative abundance represented by the seven studies published during the current review period (in addition to the three driving simulator studies discussed in the previous subsection) may well reflect an increased willingness on the part of alcohol researchers to undertake investigations which are difficult, tedious, and time-consuming, but which could well have extremely important implications for real-world behavior, as well as for future experimental methodology. In this regard, it should be noted that among the four highly desirable and promising research areas recommended by Levine et al. (1973; discussed above on p. 8) were two interrelated topics which form the basis of the present section: investigations of time parameters and of the experimentally manipulated interaction of dosage and time as an influence upon performance.

ACUTE ADAPTATION TO ALCOHOL INFLUENCES

As noted in the previous subsection, Hurst and Bagley (1972) have recently published a comprehensive review of the literature concerning "acute adaptation." This concept implies a temporary rise in impairment threshold during a single drinking episode (Hurst & Bagley, 1972, p. 358). On the basis of their review, these authors concluded that "if adaption occurs, it probably does to a varying extent with different types of function. Reaction time seems least likely to show substantial adaptation, ... perceptual-motor skills are more likely candidates, ... cognitive skills may be the most sensitive of all, ... (and) finally, adaptation may take more than a few hours to show itself with some variables (Hurst & Bagley, 1972, p. 362)."

In an effort to test the acute adaptation hypothesis, Hurst and Bagley (1972) selected experimental tasks to represent the four functions above: cognition (a letter-coding task which involved aspects of attention and cognition), perceptual motor performance (standing steadiness and sitting steadiness), affect (the Nowlis Mood Adjective Check List), and judgment (a level-of-aspiration procedure used with the steadiness performance scores). Hurst and Bagley reported two experiments, the second of which was an improved and modified replication of the first; but since the results of their second experiment are "much stronger statistically and should be given the greater weight" according to the investigators, only this later experiment is considered here.

Hurst and Bagley's second experiment was especially well controlled and counterbalanced to maximize appropriate testing of the acute adaptation hypothesis. A simple cross-over design was used to balance the two treatment orders (no beverage versus 0.85 g alcohol/kg body weight) over the 36 young subjects (6 of whom were female for some unexplained reason). A monetary bonus schedule with a premium for good performance was used "to insure that the subjects attached similar importance to the alcohol and control sessions." Subjects were allowed 12 minutes to consume the alcoholic beverage (bourbon and carbonated mix) and were started on the 240-minute test sequence 15 minutes after ingestion of the alcohol. Each subject received 7 Breathalyzer tests, beginning 15 minutes after alcohol consumption and thereafter at 30-minute intervals up to the 135-minute test and then at hourly intervals. The mean BAC peak was approximately 80 mg/100 ml and was reached between the third and fourth trials, that is, between 75 and 105 minutes after completion of drinking.

Hurst and Bagley have presented an excellent exposition of the major methodological problems in analyzing data from these kinds of designs to test the adaptation hypothesis (1972, p. 371-372). For their analyses, these investigators elected to compare the set of "rising phase" trials with selected combinations or subsets of "falling phase" trials. Significantly greater alcohol impairment during the rising phase (trials 1 to 3) than on the various subsets of falling phase trials was obtained both for the attentional coding task and for the standing steadiness task (the sitting steadiness task having been exluded from this second experiment). Regarding the self-ratings of mood, the rising phase aggregate showed greater reductions on only two dimensions: Insecurity and Depression. Hurst and Bagley concluded that the joint results of both experiments generally support the adaptation hypothesis, such that both the cognitive performance (coding) and the perceptual-motor measure (standing steadiness) undergo acute adaptation to alcohol impairment, whereas changes in self-rated affect suggest such an influence. They noted that if adaptation size is defined in terms of initial impairment, then it appears that both the coding and standing steadiness tests show about 40% to 50% recovery at equivalent BACs during the falling phase.

Hurst and Bagley suggest a fascinating if tentative implication for drinking and driving: although their data do not suggest that "adaptation" can bring about full recovery of performance at higher BACs, the degree of impairment at any given BAC may nevertheless be substantially reduced. "To wait an hour after the last drink before driving home might eliminate about half of the impairment effect, a much greater gain than would be expected from the smaller BAC reduction thus effected. This mild deprivation should be more readily accepted by social drinkers than most current, officially prescribed formulas (Hurst & Bagley, 1972, p. 377)." The possible utility of this procedure as a countermeasure clearly warrants further research under real-world conditions.

Wilhelmi, Lindner, and Audrlický (1972) investigated acute adapatation to alcohol influences in three major aspects of twilight (mesopic) vision, namely, static acuity before, during, and after intense light stimulation. Using appropriate psychophysical procedures and a Mesoptometer for projecting Landolt rings at specified levels of contrast against two different low intensities of background, they obtained baseline measures of mesopic static acuity prior to alcohol ingestion, as well as measures of glare resistance and glare recovery at selected time points following ingestion. The 29 subjects (13 of whom were female) ranged in age from 19 to 45 years and were all screened for three relevant visual parameters prior to baseline testing. The subjects were allowed to select from the standard spirits (76 proof in Germany) mixed with a bit of fruit juice, administered on the basis of 0.9 to 1.0 g alcohol/kg adaptation size is defined in terms of initial impairment, then it appears that both the coding and standing steadiness tests show about 40% to 50% recovery at equivalent BACs during the falling phase.

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RESEARCH TRENDS, NEEDS, AND PRIORITIES

By way of conclusion and in order to relate the reviewed research and the interrelated current problems to the future, this final section is concerned with outlining the major research trends, needs, and priorities. Considered first are a few of the more important trends which have been developing and/or culminating in recent years. Next, the research needs suggested by recent reviewers are summarized. The final subsection consists of a brief summary of a recent investigation in which specialists rated priorities for basic research and applied research in the area of alcohol and highway safety.

RECENT RESEARCH TRENDS

During the course of reviewing the recent literature concerning alcohol experiments on driving-related behavior, four relatively interrelated trends of major importance became apparent. The first -- and probably the most obvious -- can be characterized in terms of greatly increased interest and activity in investigating behavioral -- as opposed to epidemiologic -- aspects of the role of alcohol in highway safety. This shift in research emphasis, plus the relatively high level of activity, might be interpreted as pragmatic recognition that the remaining increase in understanding -- and eventual control -- of the "drinking-and-driving problem" is potentially greater from behavioral and psychopharmocologic research than from epidemiologic research. In other words, given the proportionally greater contributions from epidemiologic studies to date, there is perhaps relatively much less potential gain still possible from this approach, whereas the knowledge gap remaining in the behavioral domain is enormous. Although behavioral research in this area has clearly lagged behind epidemiologic research, it has thereby benefited from the heuristic value of the previous epidemiologic studies which have provided a basis for formulating hypotheses to be tested in controlled experiments. Furthermore, this recent shift in research emphasis would seem perfectly appropriate since the bulk of the "drinking-and-driving problem" apparently stems from the behavior of drivers.

The second major trend in this area manifests itself in terms of increasing specificity of research on exact alcohol influences upon key variables. This trend indicates that the state of the art is becoming sufficiently well developed to provide a promising basis for serious attempts at model building. A fine example of both aspects of this development is provided by Huntley's (1973c) research on the nature and locus of alcohol effects in the information-processing sequence. Other key topics for which a relatively high degree of specificity is being achieved are: attention, adaptative assessment techniques, and acute adaptation.

The third important trend consists of the enormous improvements in the sophistication and rigor of the experimental designs, controls, and procedures being utilized in alcohol experiments during recent years. Nevertheless, the alcohol literature continues to be unfortunately cluttered with reports of poorly formulated, inadequately controlled, and/or improperly interpreted studies.

The fourth trend has obvious pragmatic importance; it consists of an appreciable increase in government-sponsored research activities in this area. This increase is due in large measure to official recognition of the enormous contribution of alcohol to driving problems. The two governmental agencies which have major research programs concerned with alcohol and highway safety are the National Institute on Alcohol Abuse and Alcoholism (NIAAA) and the National Highway Traffic Safety Administration (NHTSA). Cooperative activities between the NIAAA and NHTSA on selected aspects of this problem area have been greatly facilitated in recent years by an official interagency agreement. Detailed presentation of these programs is far beyond the scope of the present review; however, since it is difficult to obtain an overview of these activities from any single publication, the barest essence of current research activities sponsored by these two agencies can at least be offered here.

A summary of activities by two branches of NIAAA with respect to the drinking-and-driving problem has recently been presented by Pawlowski (1974). First, he mentioned the Special Projects Branch which has an administrative unit working closely with the Alcohol Safety Action Program (ASAP) activities of NHTSA to provide funds to the particular local community for a treatment program to be conducted in connection with the ASAP activities. As of 1972, NIAAA funds had been received by 25 ASAP sites. Secondly, he mentioned the Extramural Research Branch which funds basic and applied research in all aspects of alcohol use and abuse. Of 156 grants awarded by this branch during FY 1972, eight grants concerned one aspect or another of drinking and driving. The primary objectives of each of these eight research grants has been summarized by Pawlowski (1974), and the titles are listed here to provide at least an impression of the major key-words involved: (1) Alcohol influences upon perceptual-cognitive behavior; (2)

Effects of alcohol on selective attention; (3) The effects of alcohol on safe driving skills; (4) Alcohol intake, search activity, and driver performance; (5) Measures of alcohol-produced behavioral impairment; (6) Drinking and social stress in driving of young adults; (7) Drunk drivers: The development of a structured evaluation; and (8) Increasing penal sanctions and the drunk driver (Pawlowski, 1974, p. 282). Some of the results and preliminary findings from these research grants have been included and discussed in the preceeding sections.

The more behaviorally oriented research funded by NHTSA comes under the auspices of the Human Performance Branch of the Traffic Research Institute. The contract research sponsored by the latter organization is distinguished from the activities of NHTSA's Office of Alcohol Countermeasures which is concerned with the demonstration and action projects associated with the ASAPs. The more relevant of the current research activities of the Traffic Research Institute bear the following titles: (1) On-the-road driving behavior and breath alcohol concentration; (2) Alcohol and the driver's decision-making behavior; (3) Effects of marijuana and alcohol on the driver's visual search performance; (4) Comparison of alcohol involvement in exposed and injured drivers; (5) Analysis of the behavioral characteristics of high risk drivers; (6) Alcohol in pedestrian accidents; and (7) Effect of lower drinking age on youth-crash involvement. Recently, NHTSA sponsored a special project in which an attempt was made to use present knowledge -- determined by previous and current research -- as the basis for establishing relative priorities for basic and applied research in the future (Perrine, 1974a, 1974c). The results of this special project are summarized below in the final subsection.

In conclusion, one very important subtrend within this fourth major trend should be particularly noted because of its immense potential influence upon future research in this area. This subtrend can be characterized in terms of increasing government control of research directions and activities by virtue of an increase in funding by means of research contracts, as opposed to research grants. Without attempting to describe the complexities of these processes, suffice it to oversimplify and focus upon the crucial difference between the two types of funding: the source of the research ideas and problems to be investigated. In the case of grants, the problem is selected, structured, and proposed to the government agency by a specialized researcher in the field, typically a faculty member at a university. Such grant proposals are critically reviewed for the government agency by independent study committees comprised of recognized specialists in the particular area, typically drawn from the academic community.

In sharp contrast to this grant procedure, the ideas and problems to be investigated under research contracts are selected, structured, and specified by the government agency itself; they are typically initiated by one or two government employees who are more or less specialized in the area to be funded. Not only does such an individual initiate and specify the research topic, he also typically serves as one of the prime reviewers of the proposals submitted in response to the "request for proposal" and then subsequently serves as the "contract technical manager" of the particular project once it is funded. Thus, the success of this "RFP approach" to research is largely dependent upon the specialized knowledge and ingenuity of the government employee. Furthermore, an increase in the proportion of government-initiated research contracts probably means a decrease in the proportion of research activity stemming from the initiative and ingenuity of the nongovernmental research scholars who are actually and professionally involved in the research itself.

RESEARCH NEEDS

A number of the authors of the recent reviews discussed above have commented on various research needs stemming from their specialized surveys of selected segments of the alcohol literature. Those observations of more general interest and of relevance for the present review are summarized in this subsection. In addition, notions concerning research needs which have arisen during the course of the present review are also noted.

The most pressing general needs stem from the facts that there have been very few systematic programs of continuing, focused, behavioral research concerning alcohol influences upon driving-related behavior, and virtually no models. In this regard, Perrine has stated that:

> Perhaps more so than with any other specialty in behavioral science, the alcohol literature seems to be cluttered with the bones of isolated, poorly controlled, one-shot studies by investigators who were probably just curious about what happens when alcohol is simply added as a treatment condition in an area of research which they had already been pursuing. Thus, the greatest single need appears to be a willingness on the part of investigators to develop and then to pursue a line of research in sufficient depth to permit definitive statements to be made about the particular topic or subtopic which they are examining. (1974a, p. 14)

Addressing himself to more specific aspects of the same general problem, Barry has stated:

> With regard to methods in conducting laboratory experiments, large-scale research is very scarce and badly needed. A comprehensive study should include several doses, with tests at a wide range of time intervals. . . . Systematic, carefully controlled experiments, with appropriate tests conducted on an adequate number of subjects, would yield standard, quantitative data which would increase the scope and, in particular, the

> trustworthiness of our knowledge about the effects of alcohol.
>
> Contrary to these desirable characteristics, most experiments have been with one or two alcohol doses, tested over a limited time-interval in a small number of subjects. There should be sufficient incentive for undertaking the needed large-scale, parametric experiments. One such study would have greater impact -- and would be cited much more often -- than a dozen additional small studies of the usual type. (1974, pp. 89-90)

The unique and innovative approach to the literature offered by Levine et al. (1973) was discussed in relatively great detail above, especially regarding their recommendations for future research (see p. 8 above). Levine et al. (1973) felt that research on the following topics would be highly desirable: practice effects, time parameters, the experimentally manipulated interaction of dosage and time as an influence upon performance, and the effects of alcohol upon task performance of heavy drinkers and alcohol-dependent individuals. They also recommended that alcohol research "should be concentrated on the tasks which tap some underlying behavioral mechanism, such as attention, memory, etc., and which simulate aspects of performance which are commonly required in real-life situations (Levine et al., 1973, p. 29)." They also rather strongly recommended that future research employ indices of performance which are commonly used in psychological research, but which are frequently neglected in alcohol research, namely, accuracy and speed of performance.

Following his review of selected aspects of alcohol influences upon sensory-motor functions, visual perception, and attention, Moskowitz recommended that:

> If any conclusion can be derived from this review, it is that drivers under the influence of alcohol have their information-processing capacity reduced and thus must re-

strict some of their information inputs which might normally have been processed concurrently. Questions which arise from this conclusion include the following: what determines the strategy for selection of inputs for attention under the restricting influence of alcohol? For example, how does alcohol affect the patterns of visual search which typically characterize the driving situation? Such knowledge could assist in developing better techniques for communicating the presence of potential danger to the driver under the influence of alcohol.

It would appear that limits on information processing are at the heart of the problem, but little is known about what specific aspects of information processing are affected by alcohol. Greater knowledge of what specific central processes are affected by alcohol might assist in developing techniques of presenting information necessary for the driving task so that it is less susceptible to disruption by the presence of alcohol.

One factor in considering future investigations is the greater inclusion of subjects drawn from the heavy drinking groups in the population. As Allsop (1966) has demonstrated, accident probabilities as a function of BACs differ depending on the frequency of drinking practices. Most studies examined in this review utilize the readily available sample of student subjects. While general conclusions would not likely change with other drinking populations, estimate of BAC where significant changes in performance decrements occur would be likely to be a function of drinking practices. (Moskowitz, 1974, p. 64)

Regarding alcohol influences upon the more motivational and cognitive aspects of behavior, Barry has suggested that:

A particular need is for experiments under conditions which simulate the situation of driving, especially performance of routine, well-learned tasks for a prolonged duration. Effects of alcohol should be tested under the normal conditions and also in response to sudden stimuli which simulate emergencies.

Large-scale experiments should be undertaken, including tests with several doses and at a wide range of time intervals. There has been very little research on the hangover effect, at 12-24 hours after consumption of alcohol. Also, more research is needed on sex differences and other characteristics which give rise to differences among individuals in response to alcohol.

> Four principal motivational effects of alcohol should be studied: (a) emotional unresponsiveness; (b) suicidal and other self-destructive behavior; (c) decrease in fear and increase in risk taking; (d) increased assertiveness, including hostility and power needs. Four principal cognitive effects of alcohol should be studied: (a) short-term memory loss; (b) tests of reasoning and problem solving; (c) dissociation between the intoxicated and sober state; (d) impaired perception of the detrimental effects on one's own performance. (Barry, 1974, p. 92)

Regarding alcohol influences upon closed-course driving performance, Huntley offered the following suggestions for future research:

> A review of the alcohol-and-driving literature leaves the impression that many studies have been more concerned with demonstrating that alcohol impairs driving performance in some way, rather than with trying to gain an understanding of the mechanisms through which such impairment occurs.
>
> Granted, it is important to know that some low BAC reduces driving skill. However, an understanding of the process would be even more useful, in that it is more likely to indicate a means of guarding against alcohol effects. If such an understanding is to be achieved, alcohol research must become more systematic and intensive. Rather than looking at impairment only from the molar perspective of system output (e.g., in terms of tracking accuracy) as has often been done in the past, the relatively recent interest in the effects of alcohol on the psychological components (e.g., sensitivity to feed back, visual search, etc.) upon which system output is dependent should be encouraged and intensified.
>
> Furthermore, the fact that the effects of alcohol are modified by individual differences, the nature of the driving task, and sleep deprivation emphasizes the complicated nature of the effects of alcohol upon behavior and indicates the need for additional research on the interactions of alcohol and other variables with which it is likely to be combined.
>
> Considering the contribution of the particular driving task investigated to the aspects of driving effected by alcohol and the fact that the results of these studies must eventually be generalized to the real world, the

> importance of conducting the research in situations closely approximating real-world conditions and of studying behaviors directly related to actual driving performance must be emphasized. In view of the demonstrated sensitivity of control-use behavior to the physiological and attentional states of the driver, the logical relation of such activities to driving, and their unobtrusiveness, the continued use of such measures should be encouraged in driving research. However, until control-use patterns have been directly related to driving performance (e.g., tracking precision), their usefulness will not be fully realized.
>
> Given validated measures, rigorous experimental procedures, realistic tasks, a commitment to understanding the effects of alcohol on driving, and time, it should be possible to obtain information which will be useful in modifying drinking-and-driving behavior and the driving environment to a degree which will substantially reduce the current annual rate of alcohol-associated driving fatalities. (Huntley, 1974, pp. 122-123)

A potential countermeasure for drinking-and-driving problems was discussed above in terms of acute adaptation (Hurst & Bagley, 1972). Regarding the possible savings from acute tolerance (i.e., adaptation or "Mellanby effect"), Hurst has recently stated that:

> At least for some behavioral measures, impairment seems to be less during the falling phase of BAC than it is during the rising phase, when BAC itself, as well as practice, fatigue, etc., are equated. It would be difficult to translate such findings into modifications of chemical test statutes, if indeed they are applicable to real driving situations. However, there is a potential educational value. A brief period of abstinence (1/2 to 1 hour) after the last drink at a party might pay off in considerably reduced driving hazard, even if not in the ability to pass a Breathalyzer test. I would advocate, as a first step, some simulation and/or test track studies to determine whether the laboratory results are applicable to the skills involved in driving, and whether they interact with practice and fatigue. It is also possible that "carryover" exists, as originally suggested by Jellinek (1960) and supported by Kalant et al. (1971). This refers to an interaction between chronic tolerance and acute tolerance. Relative to the light drinker, the habitually heavier drinker may have slightly greater tolerance shortly after alcohol

> ingestion, but <u>much</u> greater tolerance an hour or two afterward. Thus, a brief period of abstinence before driving could be particularly valuable for those who putatively contribute the most to the DWI problem. Furthermore, such a brief abstinence (while drinking coffee, eating, etc.) might be voluntarily acceptable even though nobody is likely to sit around abstemiously for long enough to effect a material reduction in BAC. (Hurst, 1974, pp. 153-154)

Finally, in terms of both future efficiency and payoff, it would seem imperative to begin now to build models to account for alcohol influences upon the more promising variables: attention, perception, cognition, and information processing generally. The desperate need for models in this research area has been outlined by Perrine (1973b), has been endorsed and documented by Huntley (1973a, 1973c, 1974), and has been expanded by Voas to the broad real-world level: "countermeasure programs are developed directly, neither from basic research, nor from applied research, but from the models of human behavior which evolve out of these research programs (1974, p. 277)."

During the course of preparing the present review, it gradually became clear that the areas and topics selected for inclusion and discussion because they represented the most important developments in recent years also comprised the topics for which the needs for future research were greatest. Thus, despite the possible tautology involved, the following selection of topics comprises the keywords which are the recommended targets for future research. Perhaps most important in general terms is information processing, with special consideration of the subcategories: divided attention, and the nature and locus of alcohol effects, especially regarding acute adaptation. The utilization of adaptative assessment techniques seems especially promising and should be pursued under rigorous experimental conditions, especially in conjunction with selected aspects of information processing. Finally, and perhaps ultimately the most significant, there is a compelling need for rigorous research on real-world driving using unobtrusive measures obtained under naturalistic conditions. Unfortunately (but understandably), precious little research effort has been devoted to this problem, although it doubtless represents the point of greatest potential gain for problem-oriented research in the future.

PRIORITIES FOR BASIC AND APPLIED RESEARCH

Any consideration of research priorities is constrained by the very extent of knowledge at the moment. In turn, any attempt to determine the extent of present knowledge in a field is necessarily constrained by the state of the art at the moment. In October 1972, NHTSA sponsored the Vermont Symposium on Alcohol, Drugs, and Driving which had three specific aims: to assess the status of present knowledge and to consider relative priorities for both basic and applied research in those areas germane to its theme (Perrine, 1974b, 1974c).

The 35 invited specialists at the Vermont Symposium rated 176 keyword topics on 3 dimensions of alcohol, drug, and driving problems: (1) the extent of present knowledge, (2) relative priority of basic research in terms of informational yield, and (3) relative priority for applied research in highway safety. These rating efforts required approximately 22,000 individual decisions which were subsequently analyzed and which comprise the first quantified evaluations of specific aspects of these problems (Perrine, 1974c).[7] The two sets of research priority ratings (basic and applied) were constructed using the three highest rated keywords from each of the eight sessions of the Symposium.

The keywords having the highest priorities for basic alcohol research in terms of informational yield were organized into three general categories, namely: (1) alcohol influences upon basic neurophysiological activities, (2) alcohol influences upon psychological processes, and (3) alcohol influences in combination with other conditions of the organism. In the first category, the two traditional divisions of the nervous system (central and autonomic) not only received high priority ratings with high agreement among the specialists, but also were rated lowest on the extent of our present knowledge.

Regarding alcohol influences upon the second category, the psychological processes can be divided into two subcategories: (1) perceptual-attentional, and (2) cognitive. The first subcategory consists of dynamic visual acuity, visual search, and attention (intensive, selective, and divided). These psychological processes are functionally interrelated and involve what has been termed "visual information processing." The second subcategory consists of risk taking and decision making, two cognitive psychological processes which are also functionally interrelated, but are concerned with the actions or behavior resulting from the visual information processing.

Regarding alcohol influences upon the third category, the other conditions of the organism can be divided into two subcategories: (1) emotion and mood, and (2) stressors other than alcohol (e.g., fatigue). The relatively high ratings for both sets of conditions doubtless stem from recognition that any "pure" influences of alcohol can be greatly affected by the condition of the person at the moment. Stressors other than alcohol (such as noise, fatigue, other drugs, emotional upset) when combined with it can either enhance or attenuate the basic influences of alcohol. These overlays of various combinations of stressors and emotional condition were highly rated for basic research priorities, especially in studies of alcohol influences upon driving itself.

The highest priority ratings for <u>applied</u> research in highway safety were essentially the same as those for basic research, with only two differences. On the priority ratings for applied research, "autonomic nervous system" was replaced among the top three keywords by "visual adaptation (glare)", and "visual search" was replaced among the top three keywords by "time-sharing (divided attention)."

In summary, these keyword ratings from the Vermont Symposium provide an educated, consensual judgment on priorities for basic and applied research on specific aspects of highway safety. As the most quantified judgments currently available, they also represent relatively specific recommendations by this group of specialists for future research directions. However, since these keyword ratings represent forced-choice judgments on a limited pool of specific words or phrases, it has been noted that they should not be interpreted as being judgments about whole programs, whether of research or of countermeasures (Perrine, 1974b). Thus, for NHTSA, one of the primary purposes of the Symposium was to bring specialists together who had been most actively working in research and in evaluation of countermeasure programs in order to provide assistance and stimulation for the development of long-range programs of research concerning alcohol, drugs, and driving (Perrine, 1974b, 1974c; Voas, 1974).

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FOOTNOTES

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2. The following sources were searched: *Accident Analysis and Prevention; Blutalkohol; British Journal of Social and Clinical Psychology; Current Contents; Ergonomics Abstracts; Highway Safety Literature; Human Factors; Index Medicus; Journal of Experimental Psychology; Journal of Safety Research; Journal Supplement Abstract Service; Perception; Perception and Motor Skills; Psychological Abstracts; Psychological Reports; Psychopharmacologia; Quarterly Journal of Studies on Alcohol; Science.* Proceedings (or distributed papers) from the following conferences were also searched: The First Annual Conference of the National Institute on Alcohol and Alcoholism, Washington, D.C., 1971 (published 1973); The Second Annual Conference of the National Institute on Alcohol and Alcoholism, Washington, D.C., 1972 (published 1973); TRANSPO 1972 Conference on Alcohol and Traffic Safety, Washington, D.C., 1972; Vermont Symposium on Alcohol, Drugs, and Driving, Warren, Vermont, 1972 (published 1973 & 1974); Congress of the Society of Automotive Engineers, Detroit, Michigan, 1973; and The First International Conference on Driver Behaviour, Zurich, Switzerland, 1973.

3. PASAR. In mid-October 1973, a PASAR search of the literature for documents published in 1972-73 dealing with alcohol and driving-related behavior was requested from the American Psychological Association. We specified an interest in such behaviors as "visual perception, visual search, eye movements, pattern recognition, detection, identification, stimulus and response uncertainty, attention, decision making, and risk-taking."

   In early December, the PASAR print-out arrived, listing a total of 43 studies. Although many of these studies appeared in *Psychological Abstracts* during 1972-73, they were actually published in 1971 or earlier, and thus were not usable. Five studies were found to be relevant for the present review, and of these, only three had not yet been located in our own search of the literature.

4. NIAAA/NCALI. In mid-November 1973, a NIAAA/NCAIL search of the literature for documents published in the years 1972-73 dealing with alcohol and driving-related behavior was requested from the National Clearinghouse for Alcohol Information. We specified an interest in "alcohol and: neurophysiological aspects, neuromuscular aspects, sensory aspects, sensory motor aspects, visual perception, autonomic nervous system function, central nervous system function, manual motor control, walking steadiness, standing steadiness, static visual acuity, visual field, glare tolerance and recovery, adaptation, brightness sensitivity, critical flicker fusion, dynamic visual acuity, ocular motor, sensory motor coordination and speed, tracking (pursuit and compensatory), reaction time, visual search, detection, discrimination, recognition, identification, suggestion, attention, short-term memory, long-term memory, learning, cognition (problem solving, decision making, risk taking), motivation, emotion and mood, eye movements, and stimulus and response uncertainty."

   On February 5, 1974, the print-out arrived, listing a total of 105 studies. In general, the studies were not especially relevant since most dealt with alcoholism or with epidemiologic studies of alcohol-related traffic crashes. Eleven of the studies were found to be useful for the present review, and of these, only two had not yet been located in our own search of the literature.

5. In this regard, two valuable studies should be cited even though they were not included in the text of the present review because they do not meet the territorial or topical criteria. A very courageous study by Billings, Wick, Gerke, and Chase (1972) was concerned with alcohol influences (BACs of 0, 40, 80, and 120 mg/100 ml) upon pilot performance during actual flight, but under simulated instrument flight conditions. Huntley, Perrine, and Kirk (1973) investigated alcohol influences (BACs of 0 and 90 mg/100 ml) upon control-response times and brake pressure modulation by having subjects drive an instrumented car in a simulated passing maneuver on a closed course. Data from both studies provided further evidence of alcohol impairment of divided attention.

6. Landauer, Laurie, and Milner (1973); Linnoila (1973a, 1973b, 1973c); Milner and Landauer (1973a, 1973b); Osterwalder and Schmid (1973).

7. Filstead and Rossi (1973) reported on a 1973 conference which was addressed to the question, "What are the critical issues and perplexing problem areas in the field of alcohol use, alcohol problems, and alcoholism?" As indicated by this focal question, the conference was apparently much more general in scope than the Vermont Symposium on Alcohol, Drugs, and Driving and thus offered little of immediate relevance for the issue at hand: alcohol experiments on driving-related behavior.