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Literature Review

Effects of Low Doses of Alcohol on Driving-related Skills: A Review of the Evidence

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16. Abstract

A large scale review has been conducted of the experimental literature on alcohol effects on skills related to driving. This review considered 177 citations drawn from this literature, and explored the evidence of alcohol effects on reaction time, tracking, concentrated attention, divided attention performance, information processing capabilities, visual function, perception, psychomotor performance, and also on driver performance measures. Impairment in all areas was significant by BACs of 0.05% and first appeared in many areas by 0.02% to 0.03%. Thus scientific evidence suggests no lower limit can be placed on alcohol impairment of driving-related skills.

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EXECUTIVE SUMMARY

This report reviews the experimental literature on the effects of alcohol on driving-related behavior, with particular attention given to the BAC level at which impairment first appears. The information provided here is intended to contribute to decisions on appropriate BAC limits for drivers.

The study began with a series of computer searches of the literature on skills performance effects of alcohol. Five hundred and fifty seven citations were found, of which 399 publications were obtained. Of this number, 177 were used in this report, with most of the remaining studies not included for one of the following reasons: the behavioral area was not considered relevant to driving, insufficient methodological detail was provided, or the publication was not available in English. For the 177 selected studies, the authors have calculated BACs at the time behavioral tests were administered, based on the reported dosages. Using details of gender and body weight of subjects, an estimated volume of distribution for alcohol was determined assuming the mean water body weight as 49% for females and 58% for males. Then, using a 15 mg. per cent per hour metabolism rate, the BAC was computed for the time of starting behavioral testing. Since the metabolism estimate is conservative and the mean BAC estimate for the duration of testing would be lower, the estimated BAC at which impairment is reported here is also conrvative, erring on the high side.

Of the 177 studies for which computations were performed, 158 reported impairment of one or more behavioral skills at one or more BAC levels. Only 19 studies found no impairment at the levels studied. In 35 studies impairment was found at BACs of 0.04% or less. The majority of studies found impairment below 0.07%. Since the majority of studies examined only one BAC level, these results must represent an underestimation of the BAC level at which impairment begins, principally because these studies failed to examine any level below that at which they initially tested and found impairment. It seems that the determination of what BAC levels are studied is frequently made with reference to the prevailing legal BAC limit. Without drug-dose level studies, it is difficult to determine the BAC level at which impairment might initially occur.

Most of the studies considered here were published during the last decade. The BAC levels studied by these studies appear lower than those typically found in the literature from the 1940s and 1950s and, as a result, impairment is reported at significantly lower levels than in the literature of previous decades.

The studies considered here were segregated into nine behavioral categories to determine if the BAC at which impairment began was a function of the type of skills involved. The categories were: reaction time, tracking, vigilance or concentrated attention, divided attention, information processing, visual functions, perception, psychomotor skills, and driving on the road or in a simulator.

Despite some problems in assigning experimental tasks to these behavioral categories, considerable differences exist in the BAC at which impairment first appears. The area of behavior showing the largest initial rise in demonstrated impairment was divided attention performance, with the second

fastest rise in impairment found with tracking performance. Studies of vigilance showed the lowest number of findings of early impairment. Effects found for each behavioral category can be summarized as follows:

1. REACTION TIME. Impairment was found at lower BACs for complex reaction time, as compared with studies of simple reaction time. Typically impairment appeared at higher BACs than in other areas.

2. TRACKING. A majority of studies reported impairment at or below BACs of 0.05%. Differences between types of tracking tasks appeared less important than the context in which tracking performance was studied, with some studies using multi-task situations.

3. CONCENTRATED ATTENTION. Concentrated attention appeared to be the least sensitive area to alcohol impairment, with no study finding impairment below 0.05%.

4. DIVIDED ATTENTION. Most studies of divided attention found impairment at quite low BACs. Impairment began at less than 0.02%, and a majority of studies found impairment at or below 0.05%.

5. INFORMATION PROCESSING. Information processing skills appear to be impaired at relatively low BACs with most studies reporting impairment at or below 0.08%.

6. VISUAL FUNCTIONS. Studies of oculomotor control tended to show impairment at low BACs, while other visual functions such as glare recovery, visual acuity, and flicker fusion, did not appear to be impaired at low or moderate BACs when studied by themselves.

7. PERCEPTION. Studies in this area showed relatively few findings of impairment below 0.08% BAC.

8. PSYCHOMOTOR SKILLS. Tasks which required skilled motor performance and coordination were more likely to be impaired at lower BACs, while studies of other psychomotor tasks tended not to show impairment below 0.07% BAC.

9. DRIVING. A considerable variation in results was found, depending on the behavioral demands imposed by the various driving tasks.

It was concluded that there is evidence that behavioral areas relevant to driving differ in their susceptibility to impairment, with divided attention tasks most likely to be impaired at low BACs. It seems that there is no lower threshold level below which impairment does not exist for alcohol.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Major approaches to combating the drunk driving problem, particularly those devised or operated by law enforcement agencies, typically involve a reliance on deterrence. In the last few decades deterrence programs have typically sought to develop an adherence by motorists to a blood alcohol concentration (BAC) standard for driving. In most states in the United States this standard requires that the driver's blood alcohol concentration be no greater than 100mg per cent, or .10%. Before the imposition of a standard based on BAC, law enforcement officers attempted to evaluate from behavioral indicators the probable degree of impairment of drivers. Behavioral criteria were found to have several difficulties, the most important of which was the insensitivity of police officers' judgements of the degree of impairment from driving behavior and/or sobriety tests. Additionally, the driver himself had little objective basis for assessing when he was legally impaired. As evidence accumulated of the substantial correlation between degree of impairment and blood alcohol concentration, and as methods evolved which made the determination of a driver's blood alcohol concentration simple, especially from breath analysis techniques, emphasis shifted to BAC as a criterion for determining whether an individual was impaired by alcohol and thus unfit to drive. Moreover, use of this criterion made it easier to tell potential drivers roughly how much alcohol would be likely to bring them over the legal BAC limit.

In the initial period of existence of such laws, a frequently set BAC limit was 0.15%. However, in the last few decades, the standard has shifted to 0.10%, and in some states 0.08%, as epidemiological studies have demonstrated that there is a greatly increased probability of accident involvement at BACs well below 0.10%. Thus, there is evidence that in the general population, even at BACs of 0.05%, the probability of being involved in an accident has increased 100%, and for young drivers this probability has increased several hundred per cent. Some countries have instituted much lower BAC levels such as 0.02%, 0.05%, and 0.08%.

It is, of course, a public policy decision as to what BAC level will be legally permitted in drivers. On the one hand, there are the epidemiological and experimental data which indicate the BAC level at which impairment begins. On the other hand, there must be public policy decisions as to the degree of enforceability of a given level as a function of public acceptance of the degree of risk involved. The lowering of the prescribed BAC level from 0.15% to 0.10% has indicated a shift in policies as a result of increasing public unwillingness to accept the number of traffic fatalities and injuries produced by alcohol. The present review was not intended to deal directly with the issue of what BAC level should be set for legal purposes. Rather, this review provides a comprehensive study of the literature to indicate at what blood alcohol concentration impairment begins for driving-related behaviors.

The decision as to what are significant driving-related behaviors is a judgemental one made by the authors, based on experience in reviewing both the traffic safety literature and also accident records which suggest variables

involved in accident causation. These experiences have been supplemented by the published conclusions of multidisciplinary investigation teams and data analyses of police records, such as those findings reported by Clayton (1972), Perchonek (1973), Josselyn and Treat (1973), Terhune (1982), and others.

The present review will detail the results of experimentation on alcohol induced impairment as a function of the behavioral area examined. Not all behavioral areas are considered to be of equal significance in producing accidents. It is necessary to examine driver performance in terms of behavioral areas as impairments resulting from alcohol do not occur uniformly in all behaviors. Thus, some behaviors are more affected by alcohol than others. Other sections of this review will attempt to relate the areas at which impairment is most likely to occur due to the presence of alcohol with information as to the areas most important for driving and accident causation.

A large body of literature exists on the effects of alcohol on skills related to driving. This literature includes a number of major reviews, such as those by Carpenter (1962), Moskowitz (1973a) and Perrine (1973). The large body of continuing research work in the interval since these reviews were published suggested that a new assessment of the literature would be timely.

The reviews noted above concurred in the view that performance of perceptual and cognitive tasks is particularly affected by alcohol, whereas psychomotor performance appeared more resistant to alcohol impairment. Thus Moskowitz (1973a) concluded that the major impairment effects of alcohol are likely to be found on central processes which require considerable amounts of information processing. More recent developments in the literature have offered additional information on the major areas of performance impaired by alcohol, and the present study sought to assess available evidence to determine whether there is a minimum BAC beyond which impairment of driving skills can be reliably expected.

CHAPTER 2

METHOD

The aim of the present review is to consider the effects of low doses of alcohol on skills related to driving. Following the approach used by Levine, Greenbaum, and Notkin (1975), the present evaluation has sought to classify research studies by the type of experimental task used, and the dose levels of alcohol applied to subjects. To facilitate this classification, and also the handling of data from large numbers of sources, a computer database was established; Appendix A provides a brief technical description of this database system. For each study, data were extracted directly from the published article and added to the database; criteria for inclusion of articles in the database are described below.

CRITERIA FOR INCLUSION

The present review includes studies where one or more alcohol levels were used, and studies which used one or more experimental tasks considered relevant for driving. Animal studies were not included due to their limited applicability in this area and because it was considered that sufficient human studies were available in the skills areas to be discussed. Studies which used alcoholics as subjects were excluded because they were considered to be of limited and uncertain relevance to the general driving population. Further, this review provides only a partial consideration of alcohol effects on areas of performance which are not regarded as specifically related to skills required to perform the driving task; thus, alcohol effects on physical performance functions (such as reflexes, oxygen uptake and heart function), will be considered only briefly. Studies of drug-alcohol interactions and their effects on driver performance will be considered only for their evidence of alcohol effects, and then only when data have been reported for both placebo and alcohol alone conditions. Finally, it will be assumed that a sufficient case has already been made for the over-representation of drinking drivers in accident casualty populations, and epidemiological evidence will not be considered here.

As a first step in locating relevant empirical studies, listings of potentially relevant material were obtained from the databases of two major +nformation services. Major reviews in the area were also searched for appropriate citations, and to check the coverage gained from the data bases. Lists of references in available works were a further source of citations. This search procedure yielded 557 citations, of which 370 were available for detailed examination. Copies of 158 cited studies could not be obtained, and an additional 29 studies were available only in a language other than English and could not be considered. Of the 370 available articles, 94 were not considered relevant to the present study because they failed to meet one or more of the selection criteria noted in the previous paragraph, and 26 review articles were excluded because they reported no new data, so that 250 studies were considered further. In order to provide a standardized assessment of alcohol effects on performance, BACs were computed for each study on the basis of dose and procedure information reported; this computation process is

described in detail below. In 73 studies the reported information on doses and procedures was not sufficient for BACs to be computed, and these studies were excluded. Thus, the final dataset included 177 studies; Table 1 summarizes the reasons for exclusion of other studies from the analyses. Appendix B provides a list of the studies which were used in this report, both in the study sample and as a general reference.

TABLE 1

DISPOSITION OF STUDIES INCLUDED IN THE DATABASE

	Number of studies
A. STUDIES WHICH WERE NOT USED IN THE PRESENT RESULTS	
Copy not available	158
Foreign language report	29
Review article (no new data reported)	26
No alcohol alone and placebo conditions	22
Reports not considered relevant	72
Insufficient detail to compute BACs	73
Subtotal	380
B. STUDIES USED FOR PRESENT RESULTS	
Studies for which BACs were computed	177
TOTAL	557

It was not intended that the present work would constitute a complete and exhaustive review of the literature. Inevitably, due to the wide diversity of publication sources and agencies researching the field, some studies in the area will have been overlooked. However, the present sample of the literature is considered to offer a comprehensive and representative review of the existing experimental evidence.

Data on alcohol doses, time courses of experiments, variables studied, subjects, results, and other relevant material were incorporated into a new data base system, with records identified by keywords indicating the type of experimental tasks used and the types of skills investigated. Table 2 shows the major keyword values, the number of studies in the database identified under each keyword, and the number and percentage of studies in each area which were included in the final analyses. As will be seen from this table, the area of psychomotor performance included a particularly high proportion of studies which were not used for the present review, the most common reason for exclusion being the lack of relevance to driver performance.

Inevitably, some studies could usefully be categorized under more than one of these keywords, and thus some studies are represented more than once in Table 2. In particular, many articles have reported results on a battery of tests covering a number of different skill areas and it is common for such articles to be labelled as explorations of "psychomotor performance". Where a number of the keywords seemed applicable, a study was classified in terms of the experimental tasks or behaviors for which the results appeared to have the most significant implications. The sections in the present report coincide with this classification system but, where appropriate, a particular study is discussed as relevant to more than one area.

TABLE 2

TYPES OF SKILLS INVESTIGATED IN IDENTIFIED STUDIES

Primary Keyword	Number of available studies	Number of studies included in analyses	Per cent included
Reaction time	65	37	56.9
Tracking	46	28	60.9
Concentrated attention	26	7	26.9
Divided attention	20	15	75.0
Information processing	29	24	82.8
Visual function	64	28	43.8
Perception	37	22	59.5
Psychomotor performance	151	28	18.5
Driver performance	41	22	53.7
TOTAL	479	211	44.1

A major difficulty in synthesizing trends from the existing literature results from the lack of a generally used method of reporting levels of alcohol dose administration. The two most common indices are those expressed in terms of

doses in either grams or milliliters of alcohol per kilogram of subjects' body weight but some studies have quoted doses in terms of volumes of proof alcoholic spirit. The present review discusses alcohol effects using the commonly employed index of milligrams of alcohol per 100 milliliters of blood as the measure of blood alcohol concentration; this index is widely used in legal definitions of intoxication. Thus data reported in relevant studies have been used to estimate blood alcohol concentration (BAC); conversion procedures are described in detail below. The emphasis in the present review is on assessing the threshold of alcohol effects on driving related skills, and also on establishing consistency of alcohol effects, so that where a study examined more than one blood alcohol concentration, it will be discussed in terms of each BAC at which a statistically significant performance decrement was found.

DETERMINATION OF BLOOD ALCOHOL CONCENTRATION

A first examination of the 557 studies included in the present database showed that 49 per cent of the available articles specified only the administered doses of alcohol, and not the resulting blood alcohol concentrations. On the other hand, nearly all of the papers that reported measured BACs also included information on dosages. For all of the studies examined in this review, BACs were independently computed from the provided dosage information. Obviously, this assessment was necessary for those studies which indicated only the dose(s) administered. It was also apparently necessary for many other studies, especially those of less recent origin, since many of these older studies relied on breathalyzer sampling to establish BACs. As many of these studies indicated, the obtained BACs appeared unusually low in view of the doses administered. Several authors remarked that, in their experience, the breathalyzer (that is, the original breathalyzer which relies on the potassium dichromate oxidation reduction method, a variant of the Widmark technique for determining BAC levels) systematically underestimates BACs, especially at low levels. The experiences of both of the present authors are consistent with this assessment, as also are the findings of evaluations by Noordzij (1969) and Prouty and O'Neill (1971). Therefore, even for those studies which reported measured BACs, an estimated BAC was computed based on the reported dose. In the overwhelming majority of cases the estimated BAC was, in fact, greater than the reported BAC. Thus, if there is any error in the procedure, it would be a bias towards reporting impairment at higher BACs rather than lower levels. In other words, based on this procedure the present estimates of the BAC level at which impairment appears are conservative.

The present estimates of blood alcohol concentration for a given dose are based on dividing the total dose by the estimated volume of distribution. The total dose was obtained in grams of alcohol and then divided by the estimated amount of water in the body. The resulting figure, which gave grams of alcohol per milliliter of water, was then converted to grams of alcohol per milliliter of blood by multiplying by .806, since 80.6% of blood is water. The estimates of water content in the body were based on the assumption that males had 58% of their body weight in water, and females 49% of their body weight in water. These figures were derived from standard tables. It should be noted parenthetically that this number, representing the proportion of body weight which is water, is not equal to Widmark's constant which includes in it several additional factors. The figure obtained at this point would be that if the total dose were instantly absorbed and distributed throughout the body.

Obviously, this process of absorption and distribution takes time, and during that time a portion of the alcohol is metabolized. The present computations used an estimate of rate of metabolism of .015% or 15mg per cent per hour as a conservative estimate for the rate of decrease of the blood alcohol concentration from the initiation of drinking until the start of the testing period, wherever time information could be obtained from the studies. This figure is again considered a conservative one, on the basis of the experiences of the authors and also of the largest reported studies found on decreases in blood alcohol concentration over time. Thus, again, any errors of estimation would tend to make the computed blood alcohol concentration greater than the actual BAC is likely to have been and hence inflate the BAC figure at which impairment was found.

As noted above, the computation procedure employed here allowed for gender differences in the estimation of BAC. However, in a substantial number of studies no information was provided on the sex of subjects, despite the fact that gender differences in the BAC produced by a given dose have been reported in the literature for some time. Further, a number of authors appear to be unaware of such differences. Thus it was not uncommon to find authors reporting the inclusion of subjects of both sexes but apparently assuming that the subject group could be considered homogeneous in terms of the effects of dose on BAC; that is, between sex comparisons were often not reported. In many studies, selection of subjects also appears to have been conducted without consideration for gender differences, with some authors reporting the inclusion of one or two female subjects in predominantly male samples, and apparently analysing data without any consideration of the possible effects of these differences. In the case of studies where gender of subjects was not reported the BAC computation methods could not be used.

It should be noted that the first author and his colleagues have for many years been utilizing this method to calculate administered doses, and in the majority of studies conducted by this group the mean values of obtained BACs have differed by less than .005% from the desired BAC. It must be emphasized, though, that there can be considerable individual variability due to factors which are not apparent. On some occasions attempts have been made to adjust BAC figures for measures of obesity or fat content in the body, based on exterior observation, but these attempts have not been notably successful in decreasing the individual variability by more than a small amount. However, as noted above, for groups of subjects the estimates have proved very accurate. Thus, on both theoretical and empirical grounds, the present estimates of BACs can be regarded as realistic and, moreover, these estimates are conservative and, if anything, will tend to slightly overestimate the actual BACs, thus making conservative any statement about the lowest BAC at which impairment appeared.

In the articles reviewed here, dosages have been variously reported as total dose in grams of 100 per cent ethanol, total dose in grams of 95 per cent alcohol, total dose in a variety of other beverages which range from 20 to 50 per cent alcohol, dosage in terms of milliliters of alcohol administered, doses in grams per kilogram of body weight, doses in milliliters per kilogram of body weight, and dosages in ounces of alcohol. Moreover, obtained empirical measures of blood alcohol concentration have been reported in terms of milligrams per cent, micromoles, and a number of other indices. In all cases estimated blood alcohol concentrations have been calculated here in terms of milligrams of alcohol per 100 milliliters of blood, and BACs have been

estimated for the time when testing commenced. This procedure has been adopted because a considerable number of reports have not provided details of the time duration of testing. Here again, the criterion represents a conservative choice; that is, the BAC is calculated for the time when testing began rather than using the BAC at the end of testing or mean BAC for the test period. The present review will distinguish between calculated or computed BACs, as derived by the present authors from dose information by the procedures described above, and empirically obtained or given BACs as reported by the original authors. For uniformity, and acknowledging the accuracy limits of measurement devices, the tables to be presented here, and the accompanying text, show BAC figures quoted to two decimal places.

One issue which has not been systematically considered in the present study, since the required information is not commonly provided, is whether performance testing occurred while the blood alcohol concentration was increasing or decreasing, that is, whether testing was on the rising or falling limb of the BAC curve. In a majority of cases, it would seem that most testing was done on the falling curve, since many studies administered the doses in 15 to 30 minutes or more, with a further 30 minutes allowed to permit absorption before testing commenced. This assumption would tend to produce conservative estimates of impairment effects, since there is a widespread literature which has demonstrated that impairment at any given BAC is greater on the rising curve than it is on the falling curve; this phenomenon is widely known as the Mellanby effect. It must be noted however, that the procedural information provided by some authors was insufficient to allow determination of whether testing occurred on the rising or falling BAC curve, and also where in the test period the peak BAC would have been reached.

CHAPTER 3

RESULTS

Figure 1 shows the distribution of dates of publications included in this review. This figure shows that 138 (or 78.0%) of the 177 reviewed studies were published after 1970, with the highest number for any single year being published in 1975. It should be noted that the database created for the present study was compiled during the first half of 1985 so that, due to variations in publication schedules, some articles published in 1984 issues of journals may not have been available for inclusion.

The trend for the present data to be predominantly derived from articles published after 1970 may help to account for one of the interesting aspects of the findings, namely that the overwhelming majority of studies has found impairment at very low blood alcohol concentrations. By contrast, the earlier reviews by Moskowitz (1973a) and Perrine (1973) found that many of the studies dealing with the variables considered here reported impairment only at considerably higher blood alcohol concentrations. This shift in the levels at which impairment is found may be due to the older studies failing to examine lower BACs. Indeed, some older studies investigated remarkably high BACs.

However, it also seems likely that recent years have witnessed a greater sophistication regarding the behavioral variables studied and, moreover, experimental methods for examining these variables have been considerably improved. Thus, a shift from studies of muscle strength and simple sensory functions to experiments emphasizing complex psychomotor skills, perception, cognitive functions, information processing and division of attention may account for a great deal of the shift in findings. These more complex behavioral measures in more recent studies represent choices by experimenters to study variables which are based on a better conceptualization of the nature of complex performance skills such as driving. Perhaps earlier concepts of driving may have emphasized the brute force necessary for steering older, less sophisticated vehicles and for operating on the types of roads for which they were designed, and this view may have emphasized strength and simple repetition of response. However, recent increases in engine horsepower have been accompanied by the use of complex control systems such as power steering, automatic transmissions, hydraulic braking, and so on, and these developments increase the emphasis on the control capabilities rather than the strength of the driver.

In addition to such trends, there have been major developments in instrumentation for measuring performance through the use of modern electronic systems such as microprocessors, making it possible to present much more complex laboratory tasks which are more representative of the actual driving situation. There has also been an increase in the sophistication of experimenters in the administration and measurement of the alcohol treatments themselves. Thus, it is suggested that recent trends toward the detection of impairment at lower BACs is a result of four factors: a) the selection of behavioral tasks, b) the instrumental capabilities to present these more complex tasks, c) an increasing sophistication in the handling, presentation and measurement of drug treatments, and d) the inclusion of lower doses in experiments.

FIGURE 1a
NUMBER OF STUDIES SHOWING POSITIVE EFFECTS OF ALCOHOL

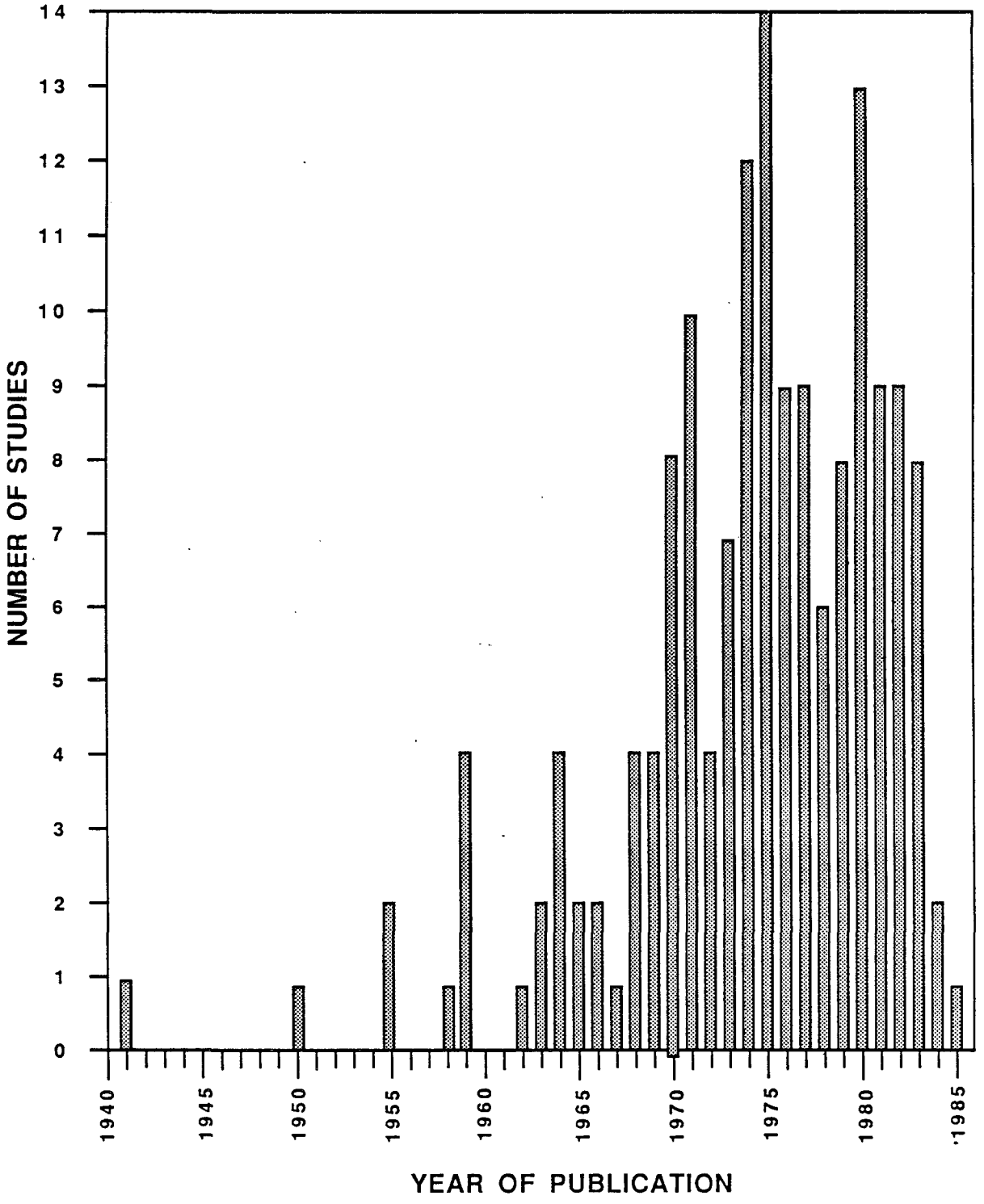
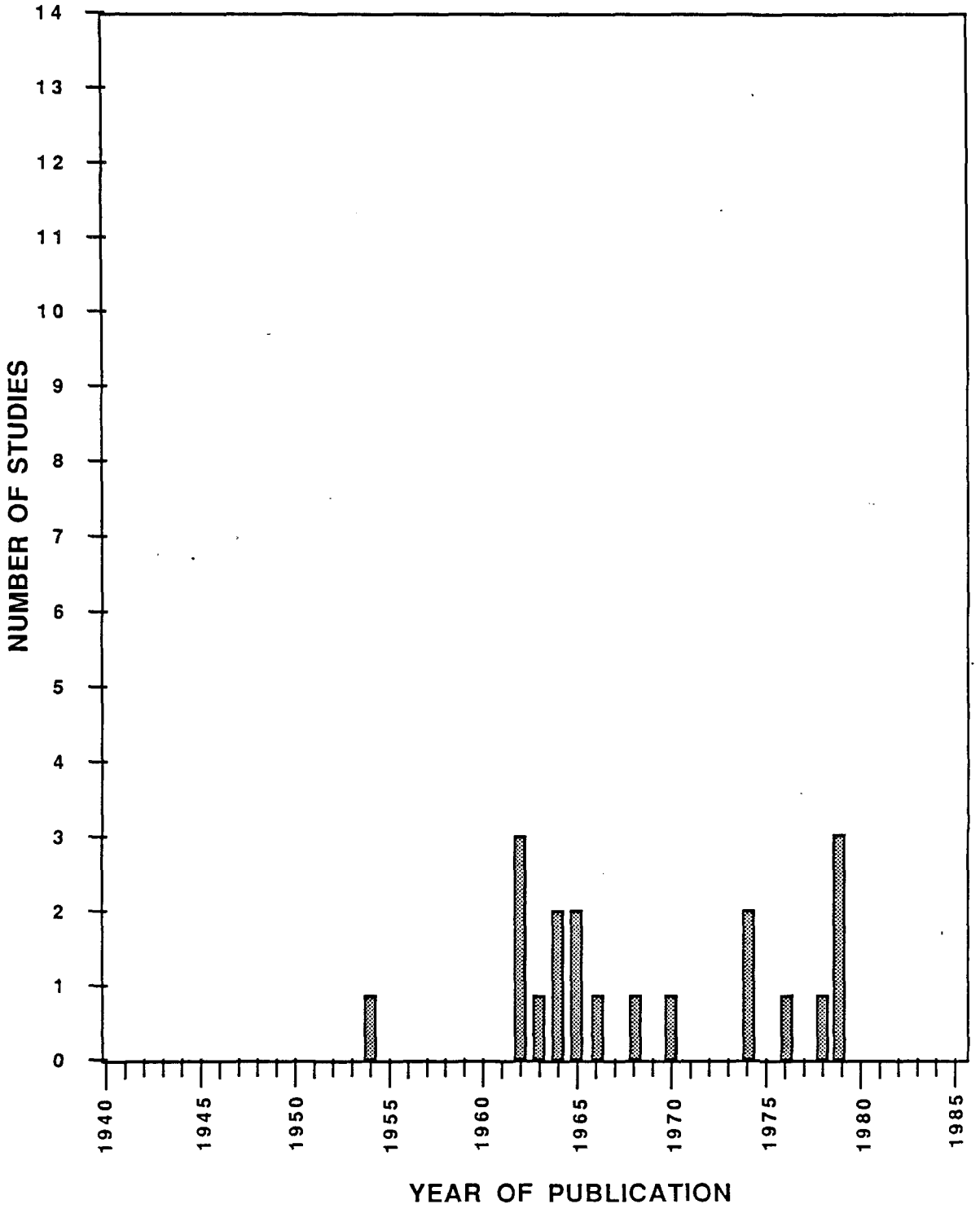


FIGURE 1b
NUMBER OF STUDIES SHOWING NO EFFECTS OF ALCOHOL



One further factor can explain some of the variability in BACs at which impairment has been reported in the studies reviewed. In contrast to most investigations reported in the pharmacological literature, studies of behavioral impairment have been performed primarily by behavioral scientists interested in the drug-behavior interaction. The typical pharmacological approach would be to examine a range of BACs so that, among other issues, results would indicate a threshold or lowest level of dose at which significant impairment would occur. The overwhelming majority of studies in the literature have used only one or two dose levels other than placebo. Often this approach has been necessitated by the high cost of human clinical research, and the difficulties involved in administering a variety of doses. Nevertheless, a consequence of this failure to examine several dose levels has been that the obtained impairment levels do not give any indication of the minimum level at which impairment might have occurred. Rather, investigators have frequently conducted their studies using what they consider a socially relevant blood alcohol concentration. Unfortunately, what is considered socially relevant differs from country to country, and differs over time, depending on each country's then current law with regard to what level is the limit at which one can legally drive. Many studies conducted in the United States have concentrated on the 0.10% BAC level, whereas in other countries with lower prescribed BACs lower levels have been explored. Thus, a conservative bias is evident in the studies reviewed here, since few have reported a lack of impairment at any level. Most studies have found impairment at the lowest level examined, which in many cases still represents a high dose level.

It could be argued that the few published studies have reported alcohol impairment due to editorial biases against publishing negative results. Were this so, it would be anticipated that the small number (19) of negative reports could be evenly or randomly distributed across behavioral areas. Yet nearly all (16) negative published studies were concerned with the single behavioral area of reaction time. This suggests that the small number of published negative findings is due to the widespread impairment of many behavioral areas by alcohol, rather than editorial bias.

The present review will concentrate on six major areas of skilled performance: reaction time, tracking, cognitive function (including vigilance, information processing, and concentrated attention), visual functions, perception, and psychomotor performance. In addition, studies which have explored alcohol effects on measures of driver performance, either in a simulator or in actual driving situations, will be considered separately. For each of these areas a table is presented showing reviewed studies which reported significant alcohol effects on performance; these studies are grouped according to the BACs at which impairments were found. Other aspects of behavior will be considered briefly at the end of this review.

The purpose here is to provide an assessment of trends in the experimental literature which bear on the question of what are the thresholds of onset of impairment. Thus the approach is to offer a synthesis of evidence rather than a detailed assessment of each cited study; for further information on a particular study, it is recommended that the reader refer to the cited original report. However, in topic areas where there is a diversity of experimental tasks or procedures, some detailed consideration of a representative selection of individual studies is provided.

REACTION TIME

Table 3 lists the studies examining reaction time measures at each BAC for which there were statistically significant findings. Figures 2 and 3 show the lowest BAC at which significant impairment was obtained for each study of simple and complex reaction time respectively. In this and the following tables, studies which reported significant effects at several BACs are cited for each BAC at which impairment was found. Repeated citations are indicated in the table by a hash mark (#). However, only the lowest BAC at which impairment occurred is included in the relevant figure; that is, each study is represented only once in the relevant figure. The figures show the numbers of studies finding impairment at the various BAC levels. Wherever possible, the task measures were classified as either simple or choice reaction time measures on the basis of descriptions provided by the authors. Simple reaction time was taken as the measure of time required for subjects to respond to a single stimulus, and choice reaction time as the measure of time to respond to one of a variety of experimental stimuli. In some cases, insufficient detail was provided for such classifications to be made, and these studies were included in Table 3 but omitted from the detailed analysis of evidence. In other cases, studies investigated alcohol effects on several reaction time measures, and in such cases each task is included in the table and in the appropriate figure(s). Two other types of reaction time measure should also be noted. Some studies used measures of complex reaction time, where reaction times were derived as part of a more complex experimental procedure, such as the Sternberg paradigm. A small number of studies investigated the components of reaction time, decision time (time taken to process the stimulus information and decide on a response) and motor movement time (time taken to implement the decision and respond). In each case where these measures were used, they are described as such in the table but not separately represented in the figures.

Of the 37 reviewed studies of reaction time, 12 studies, using 14 measures of reaction time, have reported impairment at BACs of 0.05% or less. Almost half of these studies involved simple reaction time, and a similar proportion involved choice reaction time. Sutton and Kimm (1970) explored alcohol effects on reaction times of single motor units, and found impaired responses at computed BACs as low as 0.02%.

Studies of reaction time differed from those in the other skill areas to be discussed in that there were significant numbers (16) of studies which reported finding no effects of alcohol. These studies are summarized in Figure 4, with each study represented once at the highest BAC for which no impairment was exhibited. Thus, studies failing to obtain impairment are presented at the highest BAC exhibited, in contrast to studies finding impairment which are presented at the lowest BAC exhibiting impairment.

The literature has tended to show a lack of consistency in evidence on the effects of alcohol on reaction time. Some early studies, such as that by Muller et al. (1964), indicated no consistent alcohol effects on reaction time at reported BACs below 0.10%. Thus, Carpenter (1962) noted that not all studies of reaction time had found evidence of impairment due to alcohol, and the data presented in Figure 4 indicate the substantial numbers of such findings. Carpenter noted methodological weaknesses in a number of the studies he reviewed, and concluded that simple reaction times were unlikely to be

TABLE 3

SUMMARY OF FINDINGS FOR REACTION TIME

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Sutton & Kimm (1970)	Motor unit RT
0.03		Lister & File (1983)	Simple RT
0.03		Palva et al. (1982)	Choice RT
0.03	#	Sutton & Kimm (1970)	Motor unit RT
0.04		Boyd et al. (1962)	Complex RT
0.04		Franks et al. (1976)	Simple visual RT Simple auditory RT Choice RT
0.04	#	Lister & File (1983)	Simple RT
0.05		Antebi (1982)	Choice RT
0.05		Evans et al. (1974)	Choice RT
0.05	#	Franks et al. (1976)	Simple visual RT Simple auditory RT Choice RT
0.05		Huntley (1973)	Choice RT
0.05		Linnoila et al. (1980)	Visual choice RT
0.05		Lutze & Schacher (1979)	Simple RT
0.05	#	Palva et al. (1982)	Choice RT
0.05		Taberner (1980)	Simple visual RT
0.05		Vuchinich & Sobell (1978)	Choice RT errors
0.06	#	Antebi (1982)	Choice RT
0.06	#	Boyd et al. (1962)	Complex RT
0.06	#	Palva et al. (1982)	Choice RT
0.06		Peeke et al. (1980)	Choice RT
0.06	#	Taberner (1980)	Simple visual RT
0.07		Bird et al. (1980)	Simple visual RT Simple auditory RT Choice RT
0.07		Bradshaw (1970)	Simple auditory RT
0.07	#	Franks et al. (1976)	Simple visual RT Simple auditory RT Choice RT
0.07		Oborne & Rogers (1983)	Complex RT
0.07		Mortimer & Sturgis (1975a)	Complex RT
0.07		Robinson & Peebles (1974)	Choice RT
0.07		Sturgis & Mortimer (1973)	Choice RT

TABLE 3 (Contd.)

0.07		Sutton & Burns (1971)	Simple visual RT Simple auditory RT
0.07		Zunder (1977)	Choice RT
0.08	#	Bird et al. (1980)	Simple visual RT Simple auditory RT Choice RT
0.08		Bird et al. (1982)	Simple visual RT Simple auditory RT
0.08		Carpenter (1959)	Simple visual RT
0.08	#	Evans et al. (1974)	Choice RT
0.08		Lyon et al. (1975)	Decision time
0.08	#	Mortimer & Sturgis (1975a)	Complex RT
0.08	#	Oborne & Rogers (1983)	Complex RT
0.08	#	Sturgis & Mortimer (1973)	Choice RT
0.09	#	Franks et al. (1976)	Simple visual RT Simple auditory RT Choice RT
0.09		Idestrom & Cadenius (1968)	Choice RT
0.09		Karhunen et al. (1978)	Choice RT
0.09		Kielholz et al. (1969)	Choice RT
0.09		Landauer et al. (1974)	Choice RT Serial RT
0.09	#	Linnoila et al. (1980)	Visual choice RT
0.09		Lubin (1977)	Choice RT
0.09		Moskowitz & Burns (1971)	Simple RT
0.10	#	Bird et al. (1982)	Simple visual RT Simple auditory RT
0.10	#	Evans et al. (1974)	Choice RT
0.10	#	Huntley (1973)	Choice RT
0.10	#	Idestrom & Cadenius (1968)	Choice RT
0.10	#	Karhunen et al. (1978)	Choice RT
0.10	#	Mortimer & Sturgis (1975a)	Complex RT
0.10		Moskowitz (1971)	Choice RT
0.11		Huntley (1972)	Complex RT
0.11	#	Karhunen et al. (1978)	Choice RT
0.11		Tarter et al. (1971)	Simple visual RT Simple auditory RT Choice RT
0.12	#	Bird et al. (1982)	Simple visual RT Simple auditory RT
0.13		Collins (1980)	Simple visual RT
0.13	#	Franks et al. (1976)	Simple visual RT Simple auditory RT Choice RT
0.13	#	Lubin (1977)	Choice RT
0.14	#	Linnoila et al. (1980)	Visual choice RT

TABLE 3 (Contd.)

0.14	#	Taberner (1980)	Simple visual RT
0.15	#	Mortimer & Sturgis (1975a)	Complex RT
0.15		Obitz et al. (1977)	Simple RT
0.15	#	Taberner (1980)	Simple visual RT
0.15	#	Zunder (1977)	Choice RT
0.16	#	Taberner (1980)	Simple visual RT
0.16		Young (1970)	Simple RT
0.17	#	Collins (1980)	Simple visual RT
0.17		King (1975)	Simple RT
0.17	#	Taberner (1980)	Simple visual RT
0.17	#	Young (1970)	Simple RT
0.18	#	Lyon et al. (1975)	Decision time
0.18	#	Mortimer & Sturgis (1975a)	Complex RT Decision Time
0.20	#	King (1975)	Simple RT

NUMBER OF ENTRIES IN THIS TABLE: 75 (37 studies)

\# indicates a repeated citation
RT indicates Reaction Time

FIGURE 2
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON SIMPLE REACTION TIME

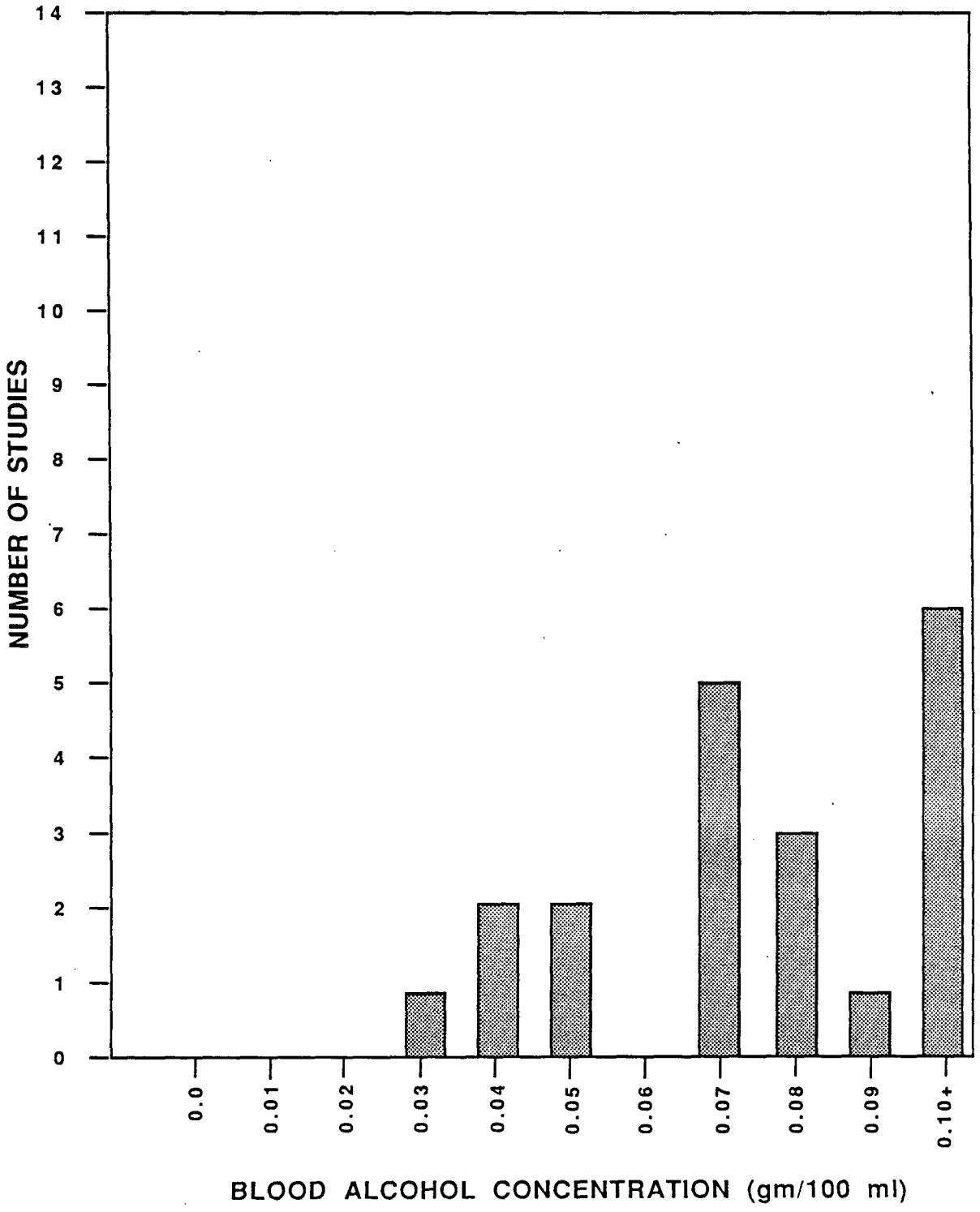


FIGURE 3
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON COMPLEX REACTION TIME

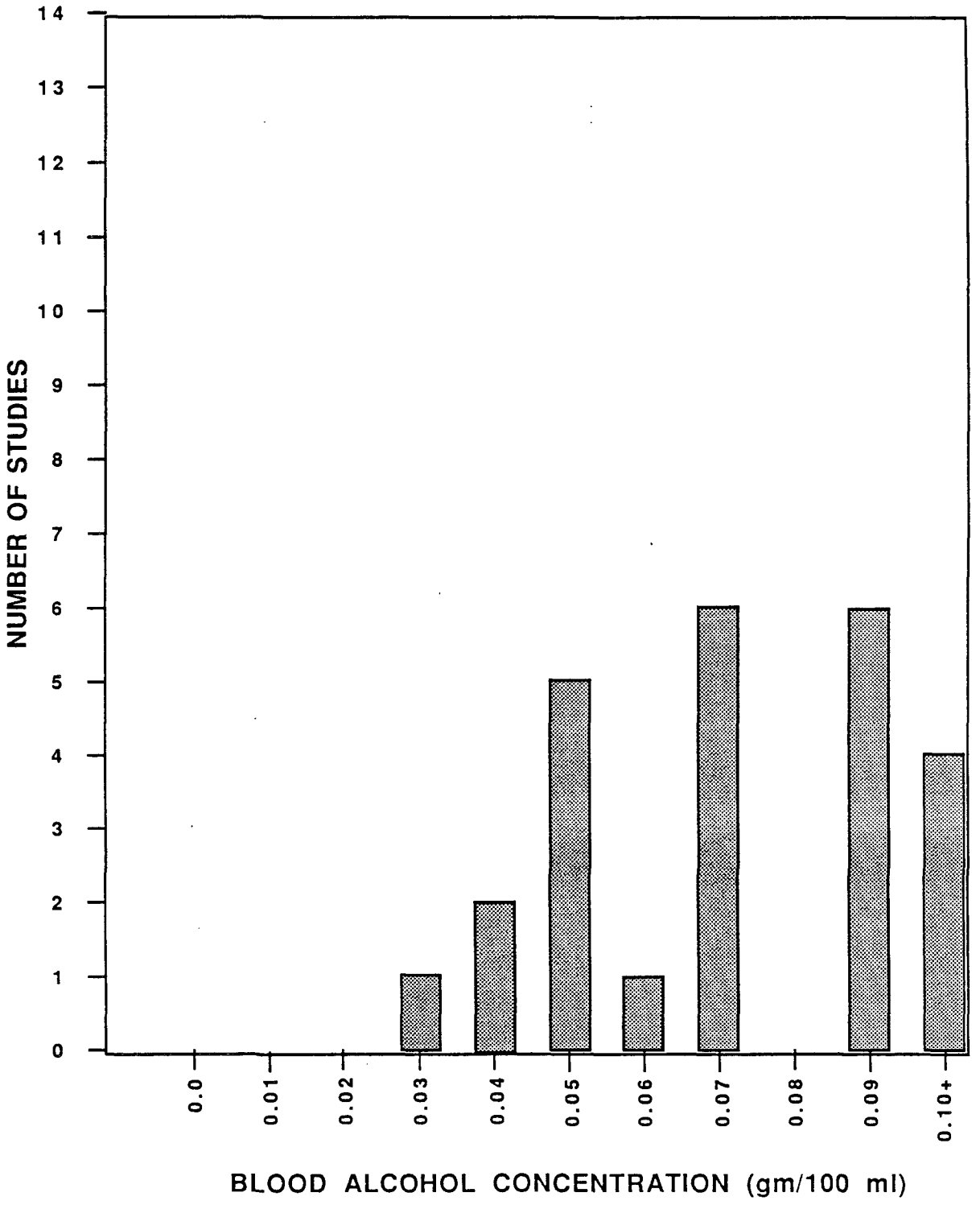
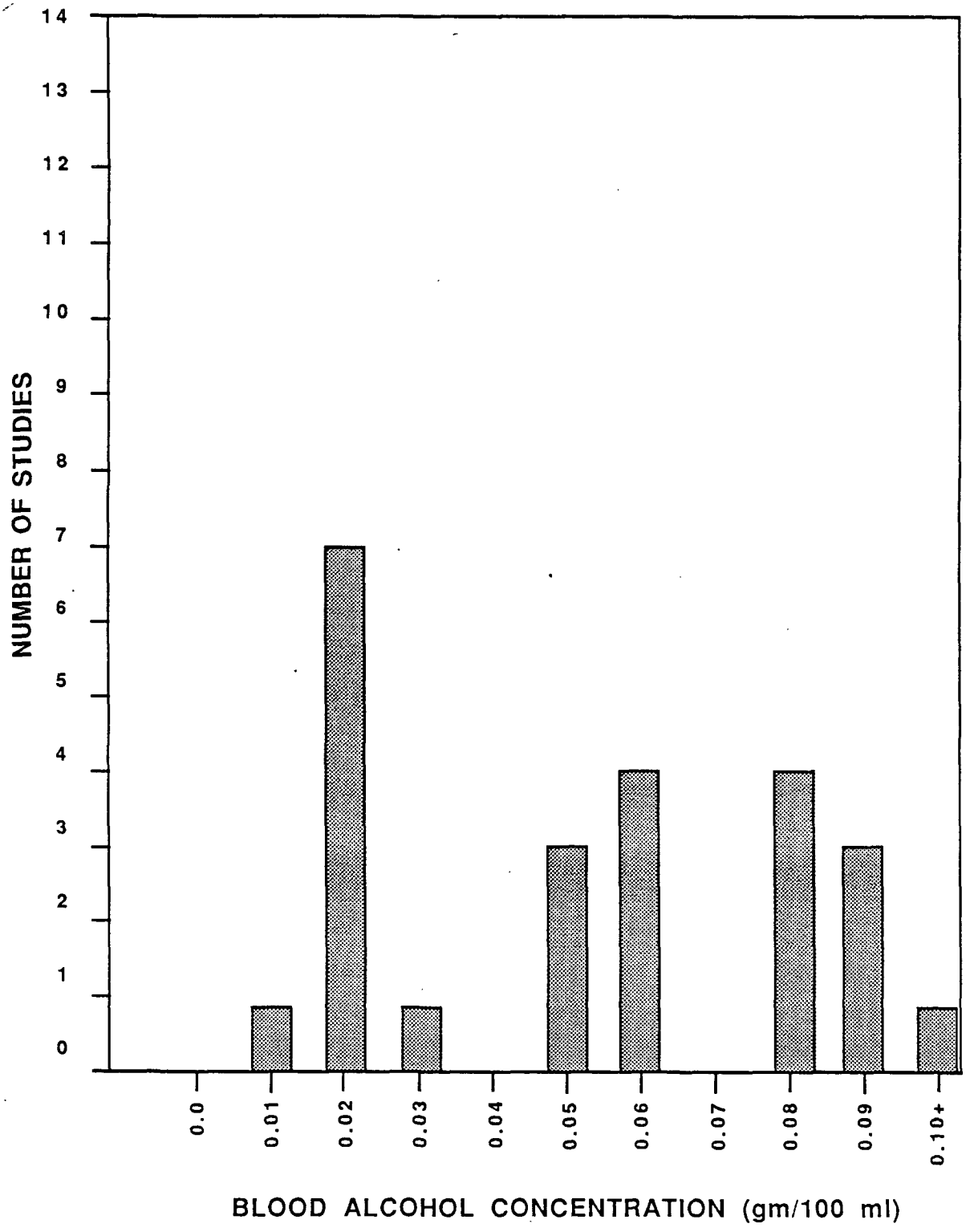


FIGURE 4
NUMBER OF STUDIES SHOWING NO IMPAIRMENT OF REACTION TIME



impaired by low doses of alcohol. Evidence presented here is consistent with this prediction.

Several of the experiments reviewed here raised issues which could account for some of the variation in results seen among studies dealing with reaction time. For example, Sutton and Burns (1971) studied reaction times of male and female subjects at several BAC levels. Females showed impairment at computed BACs as low as 0.03% while males demonstrated no impairment with BACs of 0.07%. While the authors suggested that this result may have been due to males treating the task as a competitive one, it is clear that there are other alternate explanations, given the variations in drinking experience which are likely to have been associated with gender.

Another factor introducing variability occurs if the reaction time task permits speed-accuracy tradeoffs. Thus, Shillito et al. (1974) failed to find an effect on choice reaction time at BACs of up to 0.06%. However, his data indicate that the accuracy of performing the key pressing response, used to measure reaction time, was impaired at reported BACs of 0.04% and 0.06%. Jennings et al. (1976) used a similar task and found no effects on choice reaction time or the proportion of correct responses, but at BACs of 0.09 and 0.11% subjects showed an increased willingness to trade accuracy off against speed, and also a decrease in performance efficiency. Jennings et al. reported that subjects appeared to be able to maintain reaction times under alcohol treatment by trading off accuracy for speed. They also noted that the interpretation of results from choice reaction time experiments becomes more difficult when there is a possibility that subjects have traded off accuracy for speed.

Another source of variability has been motivational factors. Obitz et al. (1977) found that simple visual-motor reaction times were impaired at computed BACs of 0.15% in a low motivation condition. However, no impairment was detected when subjects at the same BACs performed in a high motivation condition.

An additional source of variance in the BAC impairment threshold level can be seen, especially in simple reaction time experiments. The present review has relied upon authors' descriptions of experiments as a means of classifying the behavioral areas examined. Examination of some of these experiments, however, has raised questions as to whether other behavioral variables not reported by the authors, such as attention, perception, and information processing load, might not also be present in these presumed simple reaction time situations. As will be seen in later sections, these performance areas are quite sensitive to the effects of low levels of alcohol, and their presence in a simple reaction time experiment would ensure the appearance of impairment at low BAC levels. For example, Heacock and Wikle (1974) have suggested that some experiments reporting impairment of reaction time might really be the result of alcohol producing an increase in uncertainty about when to react, rather than alcohol directly impairing reaction time.

Finally, two studies reported by Moskowitz and Sharma (1974) and Lutze and Schacher (1979) used experimental procedures allowing them to consider total reaction time as two components: central time for initiating a reaction, and movement time or time for completing the reaction. Both studies reported significant impairment of reaction triggering time (seen as a reduced

likelihood of a response occurring, or else a delay in responding) at BACs of 0.05%, but these BACs showed little effect on movement time.

The results from a majority of studies, however, suggest that choice reaction times can be affected by alcohol at BACs as low as 0.03 to 0.04%, and simple reaction times at BACs of 0.04% or more. The extent of any alcohol induced effects on reaction time appears to be influenced, in part, by motivation and by the type of task, with tasks requiring accurate performance most likely to show impairment. Where subjects are able to vary their response strategies to maintain speed, and where accuracy is not a major criterion, reaction times may not increase until higher BACs (0.10% or more) are reached. Thus there is impairment by lower BAC levels, but if the experiment fails to require accuracy levels, the reaction time by itself will not reflect the impairment.

The available evidence also offers some indication of the specific functional processes in reaction time which are sensitive to alcohol effects. The motor movement components of reaction time appear relatively insensitive to alcohol, even at moderate to high doses (see, for example, Moskowitz & Sharma, 1974). Evidence from complex reaction time studies, such as those reported by Huntley (1972), Tharp et al. (1974) and others, suggests that alcohol may particularly affect the information processing components of reaction time, that is, the time required for making decisions such as the selection of an appropriate response.

TRACKING

Table 4 summarizes the evidence of BAC effects on tracking. Tracking tasks were classified into three types: compensatory tracking, critical tracking, and pursuit tracking. The distribution of findings for tracking performance for varying BACs is shown in Figures 5, 6, and 7. In recent years a number of studies of drug effects on performance have employed the Critical Tracking Task, an unstable compensatory tracking task identified in Table 4 by the abbreviation CTT.

Moskowitz (1973b) has noted that tracking performance is more readily impaired by alcohol when the tracking task is part of a divided attention situation, and some studies included in Table 4 found impairment of tracking performance within a divided attention paradigm. Nevertheless, the trends shown in Table 4 and the accompanying figures indicate that alcohol impairment of tracking performance alone has been demonstrated at BACs as low as 0.02%. Fifteen of the 28 studies shown in Table 4 have demonstrated impairment by BACs of 0.05% or less, even though there was a trend for studies in this area to concentrate on BACs of 0.05% or more.

Compensatory Tracking

Compensatory tracking occurs when an operator makes inputs to a task to maintain an index at a predetermined position; the actions required of a driver to maintain a vehicle in its lane provide an example of compensatory tracking. Findings from compensatory tracking tasks are summarized in Figure

TABLE 4

SUMMARY OF FINDINGS FOR TRACKING

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Hamilton & Copeman (1970)	Pursuit tracking under noise
0.02		Landauer & Howat (1983)	Pursuit tracking
0.03		Cherry et al. (1983)	Pursuit tracking
0.03		Collins (1980)	Compensatory tracking
0.03		Drew et al. (1959)	Compensatory tracking
0.04	#	Collins (1980)	Compensatory tracking
0.04	#	Drew et al. (1959)	Compensatory tracking
0.04		Evans et al. (1974)	Pursuit tracking
0.04	#	Landauer & Howat (1983)	Pursuit tracking
0.04		Sidell & Pless (1971)	Pursuit tracking
0.05		Beirness & Vogel-Sprott (1982)	Pursuit tracking
0.05		Collins et al. (1971)	Compensatory tracking
0.05	#	Evans et al. (1974)	Pursuit tracking
0.05		Forney et al. (1964)	Compensatory tracking
0.05		Klein & Jex (1975)	Critical tracking task
0.05		Linnoila et al. (1980)	Critical tracking task
0.05		Martin (1971)	Compensatory tracking
0.05		Vuchinich & Sobell (1978)	Pursuit tracking
0.06		Allen et al. (1975)	Compensatory tracking
0.06	#	Beirness & Vogel-Sprott (1982)	Pursuit tracking
0.06		Burford et al. (1975)	Pursuit tracking
0.06	#	Drew et al. (1959)	Compensatory tracking
0.06	#	Forney et al. (1964)	Compensatory tracking
0.06		Henry et al. (1974)	Compensatory tracking

TABLE 4 (Contd.)

0.06		Hughes & Forney (1964)	Pursuit tracking
0.07	#	Beirness & Vogel-Sprott (1982)	Pursuit tracking
0.07		Burns & Moskowitz (1980)	Critical tracking task Compensatory tracking
0.07	#	Collins et al. (1971)	Compensatory tracking
0.07	#	Evans et al. (1974)	Pursuit tracking
0.07	#	Hughes & Forney (1964)	Pursuit tracking
0.07	#	Landauer & Howat (1983)	Pursuit tracking
0.07		Linnoila et al. (1981)	Critical tracking task
0.07		Moskowitz & Burns (1981)	Compensatory tracking
0.07		Putz-Anderson et al. (1981)	Compensatory tracking
0.07		Sturgis & Mortimer (1973)	Pursuit tracking
0.07		Vogel-Sprott (1979)	Pursuit tracking
0.08	#	Beirness & Vogel-Sprott (1982)	Pursuit tracking
0.08		Burton & Jaggars (1974)	Compensatory tracking
0.08	#	Hamilton & Copeman (1970)	Pursuit tracking
0.08		Milner & Landauer (1971)	Compensatory tracking Pursuit tracking
0.08	#	Vogel-Sprott (1979)	Pursuit tracking
0.09	#	Drew et al. (1959)	Compensatory tracking
0.09	#	Evans et al. (1974)	Pursuit tracking
0.09	#	Linnoila et al. (1980)	Critical tracking task
0.09	#	Putz-Anderson et al. (1981)	Compensatory tracking
0.10	#	Henry et al. (1974)	Compensatory tracking
0.10	#	Klein & Jex (1975)	Critical tracking task
0.10	#	Sidell & Pless (1971)	Pursuit tracking
0.11	#	Allen et al. (1975)	Compensatory tracking
0.11		Chiles & Jennings (1970)	Compensatory tracking
0.12		Collins & Chiles (1980)	Compensatory tracking
0.12	#	Moskowitz & Burns (1981)	Compensatory tracking Critical tracking task
0.13	#	Burton & Jaggars (1974)	Compensatory tracking

TABLE 4 (Contd.)

0.14	#	Linnoila et al. (1980)	Critical tracking task
0.14	#	Sidell & Pless (1971)	Pursuit tracking
0.14	#	Sturgis & Mortimer (1973)	Pursuit tracking
0.15	#	Collins & Chiles (1980)	Compensatory tracking
0.17	#	Martin (1971)	Compensatory tracking
0.17	#	Sidell & Pless (1971)	Pursuit tracking
0.20	#	Sidell & Pless (1971)	Pursuit tracking

NUMBER OF ENTRIES IN THIS TABLE: 60 (28 studies)

# indicates a repeated citation.

FIGURE 5
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON COMPENSATORY TRACKING PERFORMANCE

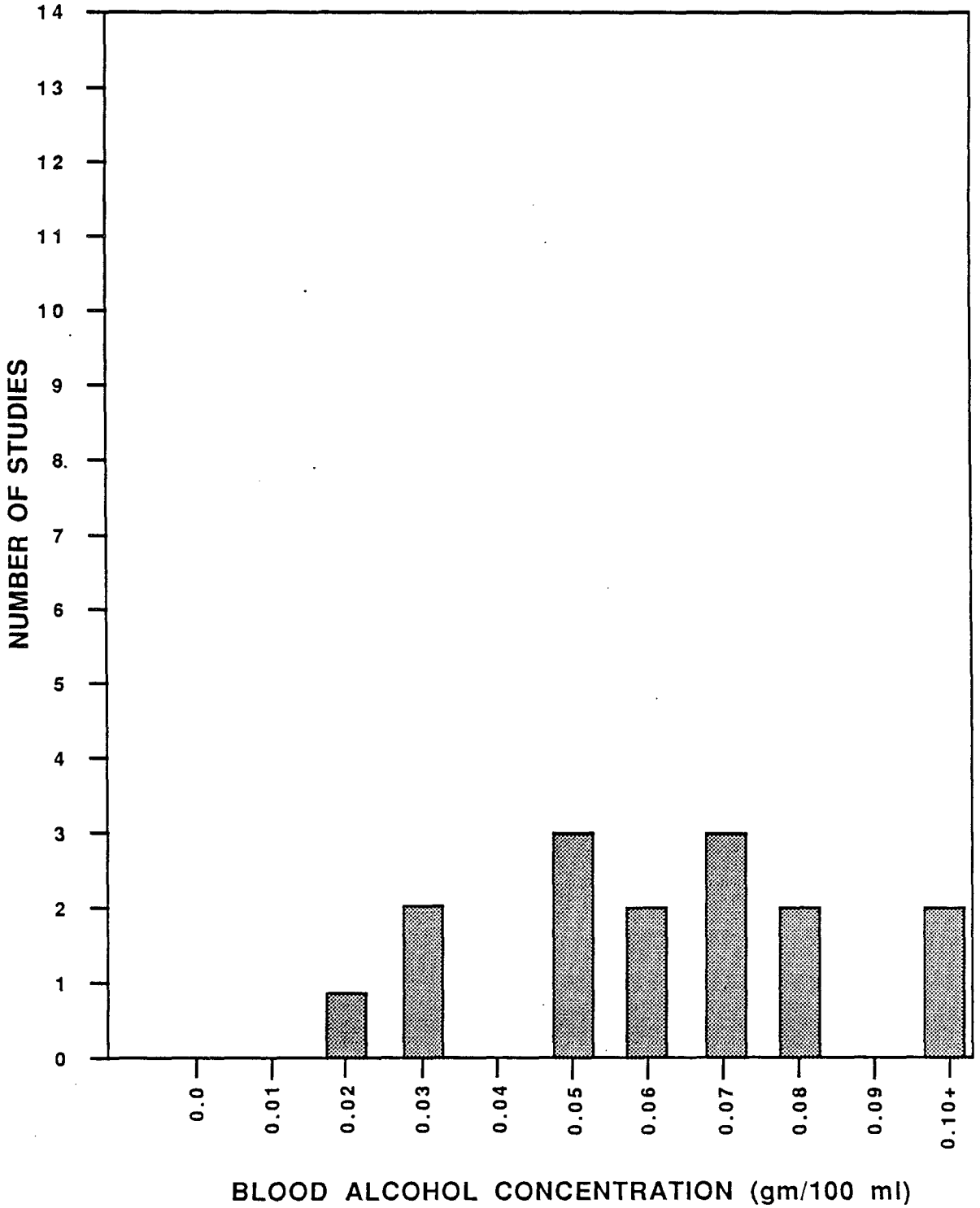


FIGURE 6
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON THE CRITICAL TRACKING TASK

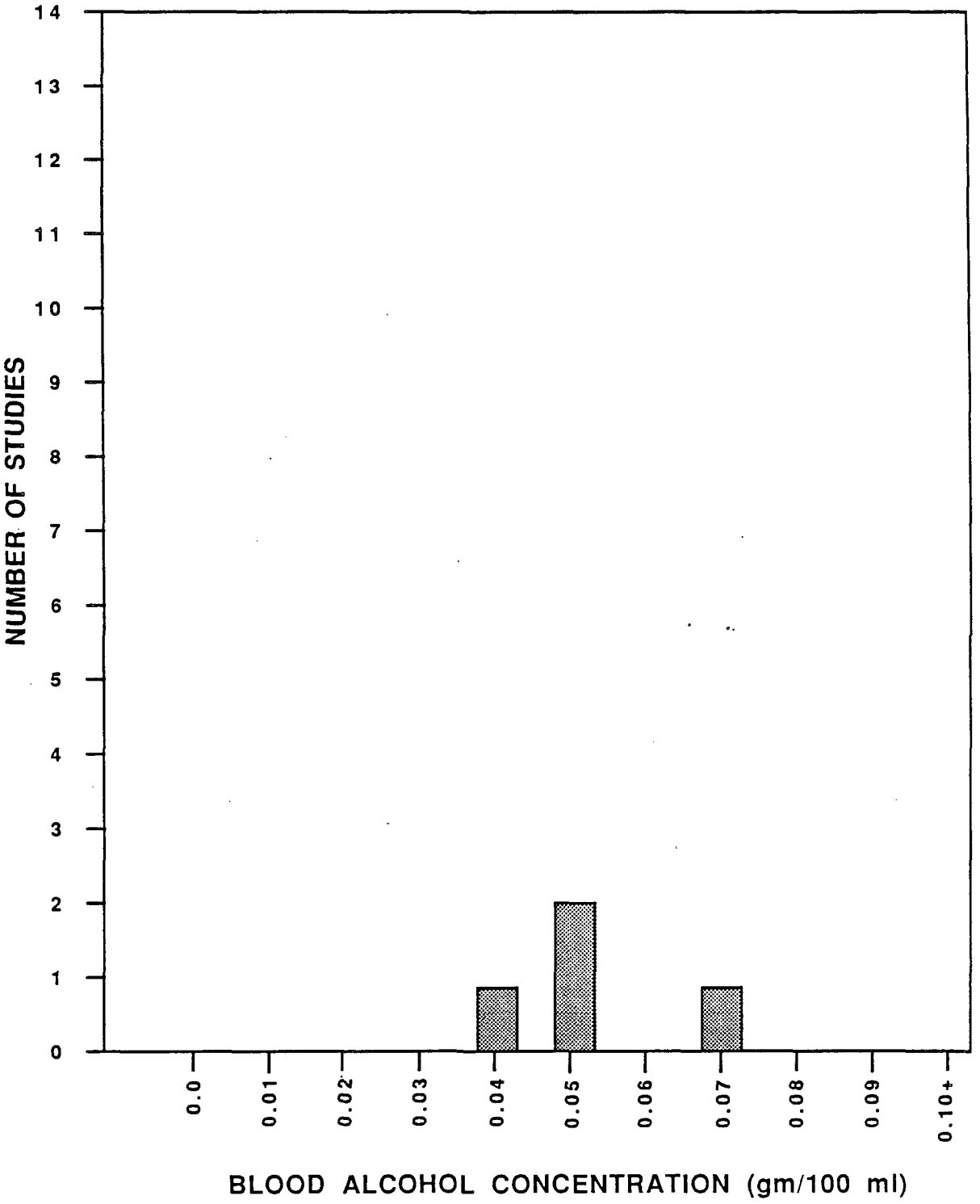
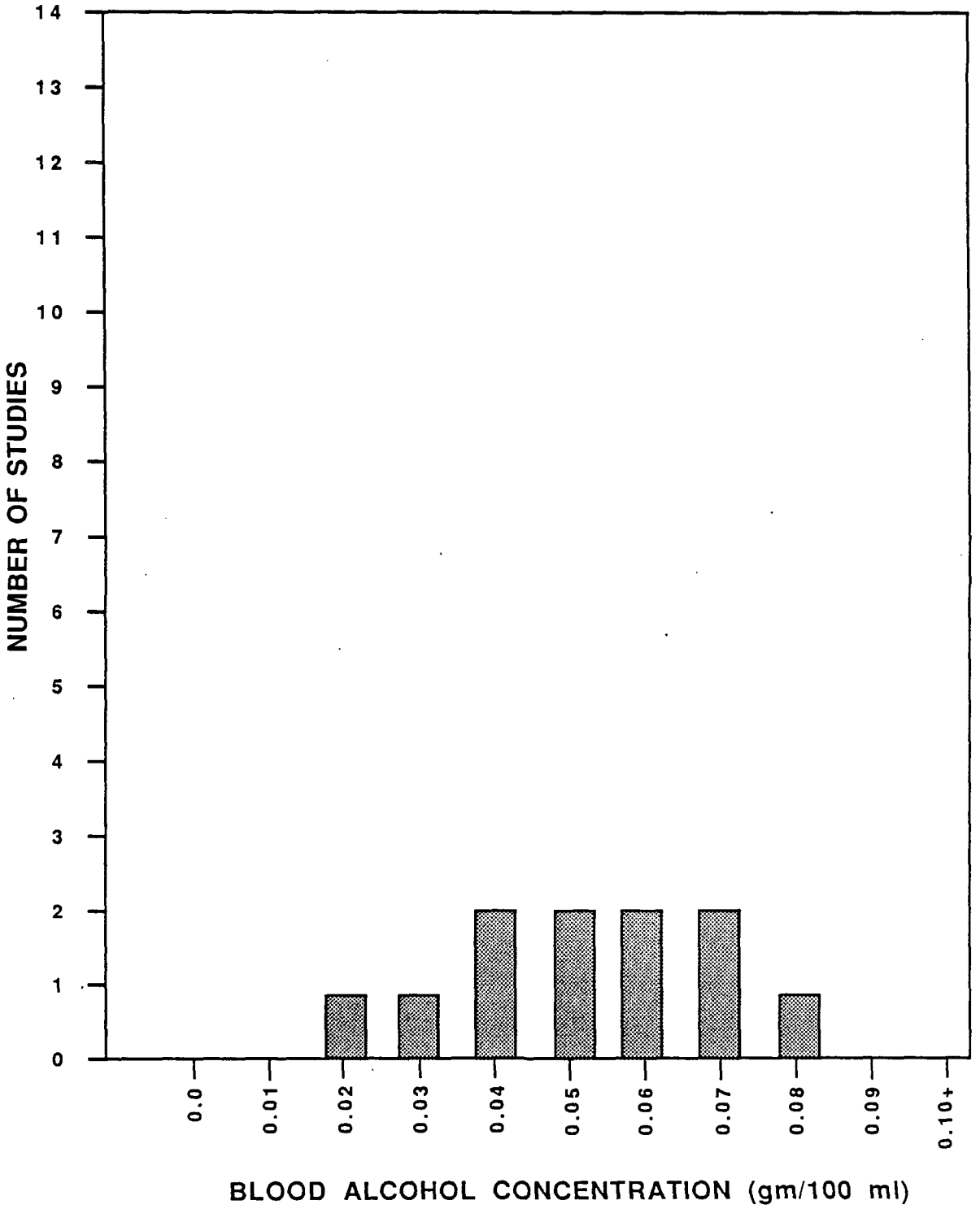


FIGURE 7
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON PURSUIT TRACKING PEFORMANCE



5, and for studies using the Critical Tracking Task, an unstable form of compensatory tracking, in Figure 6.

BACs of 0.02% and above have been found to impair compensatory tracking performance (Moskowitz et al., 1985). A total of four studies using the CTT was found in the literature, providing tests of impairment of this task at eight BAC levels, with the greatest sensitivity to alcohol being reported by Linnoila (1978) at computed BACs of 0.04%. Not all studies have reported impairment of compensatory tracking at BACs near 0.05%. For example, Collins et al. (1971) found no impairment of compensatory tracking performance at BACs of 0.05% except when subjects were exposed to substantial angular acceleration, a condition relevant to flying, but not to driving. Most studies have used BACs of 0.05% or more, and there is a substantial number of findings of impairment beyond 0.05%. Newman (1949) studied alcohol effects on a two-dimensional tracking task, and found that reported BACs of 0.08% or more were required to produce significant impairment.

Several other studies have considered alcohol effects on compensatory tracking as part of a divided attention situation. Pearson (1968) combined a compensatory tracking task with a subsidiary monitoring task, and found no impairment of tracking performance at reported BACs of 0.09%, although the monitoring task did show alcohol effects. A study by Chiles and Jennings (1970) also used compensatory tracking in combination with subsidiary tasks to study computed peak BACs of 0.11%; they found that tracking was impaired only when subjects were required to concurrently perform one of the subsidiary tasks. Results reported by Chiles and Jennings (1970), and Collins et al. (1971) have indicated that compensatory tracking is insensitive to alcohol effects when subjects can devote their attention solely to the task.

The reviewed evidence suggests that, under some circumstances, the threshold of impairment for compensatory tracking skills can be regarded as being at BACs of 0.05% or less. Further, where a compensatory tracking task is combined with another task which must be performed concurrently, both tracking performance and capacity to perform the second task may be affected.

Pursuit Tracking

Pursuit tracking requires a control index to be maintained in a constant position relative to another moving index, and hence requires a subject to attend to two or more information sources. Findings for pursuit tracking tasks are summarized in Figure 7.

Hamilton and Copeman (1970) have reported impairment of pursuit tracking performance at computed BACs as low as 0.02%. Figure 7 shows a preponderance of studies showing impairment of pursuit tracking by BACs in the range 0.05 to 0.09%.

Thus, the evidence suggests that both compensatory and pursuit tracking performance are substantially impaired by BACs of 0.05% or more. Relatively few studies have considered the effects of BACs below 0.05%, but it is clear that the onset of impairment occurs at or before a BAC of 0.05%. Moreover, under circumstances such as dual task performance it is clear that the onset of impairment occurs at BACs below 0.05%.

COGNITIVE FUNCTIONS

Concentrated Attention

Table 5 presents reviewed findings of significant alcohol effects on concentrated attention, and these findings are summarized in Figure 8. It is noteworthy that only a small number of significant findings was found, a result of the contradictory and equivocal nature of available evidence in this area. Of the seven studies shown in Table 5, none showed impairment below BACs of 0.05%. Studies to be discussed here are those which have investigated alcohol effects on intensive or continuous attention, referred to in the literature by terms including vigilance, concentration and alertness. Studies of selective or divided attention will be considered separately.

Keuchel et al. (1979) have reported sex differences in alcohol effects on concentration in an arithmetic task, with males showing decreased concentration at reported BACs of 0.03%, and females showing improved concentration at reported BACs of 0.04%. However, most studies of alcohol effects on attention suggest that BACs below 0.07% do not lead to impairment, but even the evidence on alcohol effects at BACs above this figure is confused. Richter and Hobi (1979) reported no effects of BACs of 0.04% on alertness tests. Hrouda et al. (1980) have reported that BACs of 0.07% did not affect localization of attention. Hurst and Bagley (1972) found significant impairment effects at BACs of 0.06% to 0.08%, and and Marsh (1980) found that reported BACs of 0.14% degraded performance on the Attention Diagnostic Measure.

Vigilance refers to a readiness to receive and process low levels of information over a long period of time. Colquhoun (1962) required subjects to report differences in rapidly presented visual stimuli in a task which lasted for about 60 minutes, and found no evidence of decrements in vigilance at moderate BACs. Talland et al. (1964) studied vigilance performance in chronic alcoholics after drinking, and found no evidence of impairment. Moskowitz and DePry (1968) found no effect of computed BACs of 0.06% on auditory vigilance, but did find impairment of divided attention performance at this level. Vogel-Sprott (1976) found no impairment of vigilance as part of a "coding-vigilance" task at reported BACs of 0.06 to 0.07%, even though coding performance was affected. Erwin et al. (1978) found impairment of visual vigilance at computed BACs of 0.14%, but not at 0.05 or 0.08%. Tong et al. (1980), in reviewing several of these findings, noted the importance of task duration in studies of vigilance, suggesting that the failure to find alcohol impairment may be due to the use of tasks which were not of sufficient duration. Tong et al. used an auditory vigilance task and found alcohol impairment of vigilance after 30 minutes on task at computed BACs of 0.07%. However, Docter et al. (1966) found improvement in auditory vigilance in alcoholic subjects at similar BACs using a task of 50 minutes duration.

Thus, available evidence on alcohol effects on vigilance is contradictory. Erwin et al. (1978) have suggested that the contradictory nature of the evidence may be due to variations in task types, doses of alcohol, and subject populations. It is apparent that further research is needed in this area, but the existing evidence does not reliably indicate that BACs below 0.08% impair attention or vigilance performance.

TABLE 5

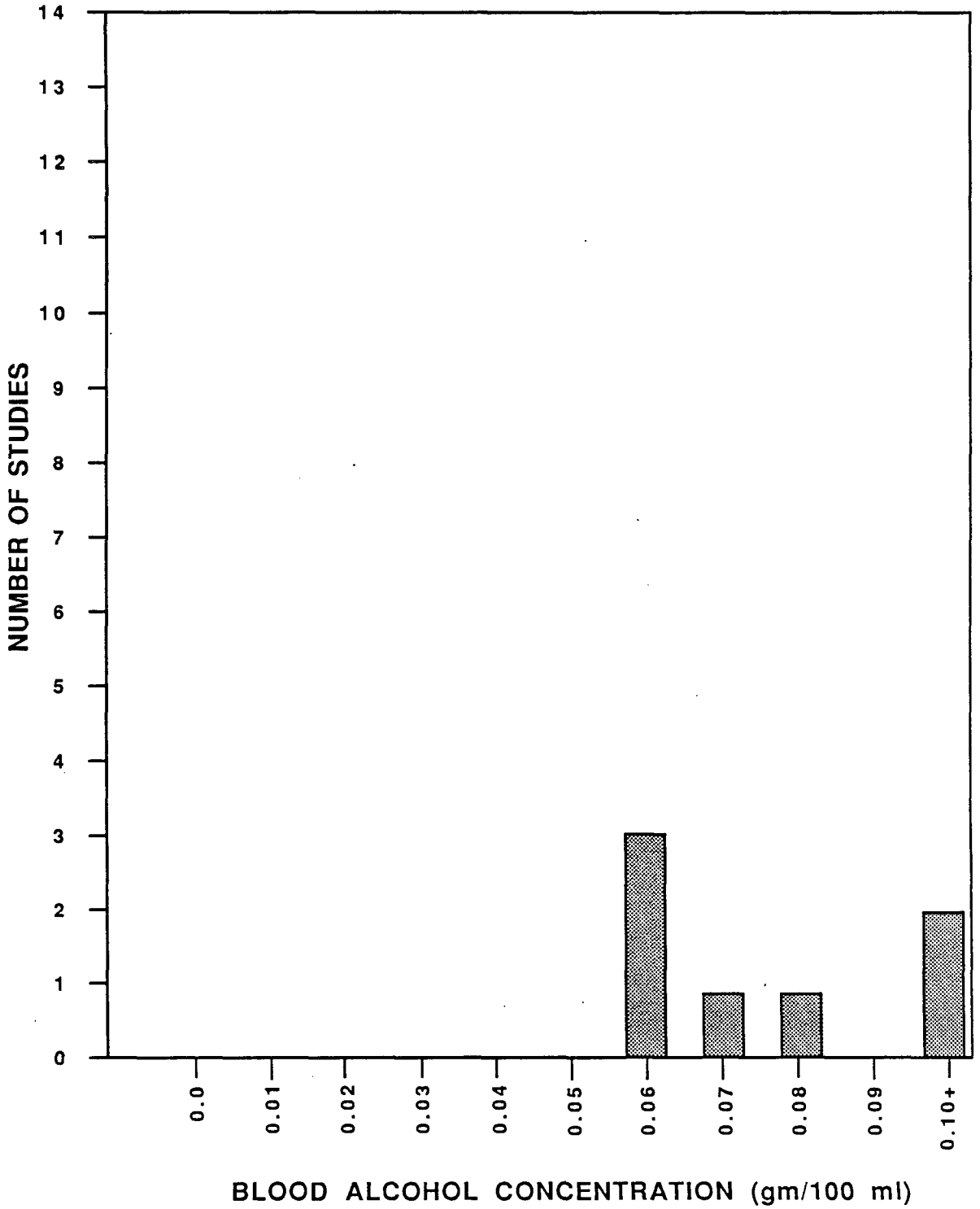
SUMMARY OF FINDINGS FOR CONCENTRATED ATTENTION

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.06		Hughes & Forney (1964)	Delayed auditory feedback performance
0.06		Hughes et al. (1963)	Delayed auditory feedback performance
0.06		Hurst & Bagley (1972)	Attention test
0.07	#	Hughes & Forney (1964)	Delayed auditory feedback performance
0.07	#	Hughes et al. (1963)	Delayed auditory feedback performance
0.07	#	Hurst & Bagley (1972)	Attention test
0.07		Tong et al. (1980)	Auditory vigilance test
0.08		Buikhuisen & Jongman (1972)	Attention to filmed traffic incidents
0.08	#	Hurst & Bagley (1972)	Attention test
0.12		Talland (1966)	Visual signal detection
0.14		Erwin et al. (1978)	Visual vigilance test
0.17	#	Erwin et al. (1978)	Visual vigilance test

NUMBER OF ENTRIES IN THIS TABLE: 12 (7 studies)

# indicates a repeated citation.

FIGURE 8
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON CONCENTRATED ATTENTION



Divided Attention

Table 6 shows the distribution of studies of divided attention included in this review; Figure 9 provides a summary of these findings. The standard experimental paradigm for divided attention studies requires that subjects perform two tasks concurrently. For each study the table shows both of the tasks used. Some studies in this area have found alcohol impairment of only one of the component tasks, and thus in the table an asterisk precedes each task which was found to be impaired at the indicated BAC, where this information could be gained from the article. It is evident from the table that most studies have found impairment of divided attention tasks at quite low BACs, with 13 of the 15 reviewed studies finding impairment at or below 0.08%. Impairment has been demonstrated at BACs as low as 0.02% (Hamilton & Copeman, 1970; Moskowitz & Shea, 1971).

Moskowitz (1973b) has described driving as a time sharing task made up of two types of activity: compensatory tracking and visual search. He has suggested that it is the requirement for divided attention which is particularly sensitive to alcohol effects. Thus, both Moskowitz and DePry (1968) and Moskowitz and Sharma (1974) examined whether alcohol produced different effects on vigilance and divided-attention performance. These studies found that BACs of 0.07% to 0.09% produced no effects on vigilance performance, but caused significant impairment of divided-attention performance.

Information Processing

Table 7 presents the reviewed findings on information processing, and these results are shown in summary form in Figure 10. This distribution suggests that information processing skills are impaired at relatively low BACs, with 18 of the 24 reviewed studies reporting impairment at or below 0.08%. Impairment of information processing capabilities has been found at BACs as low as 0.015% (Moskowitz et al., 1976; Moskowitz et al., 1985). Unfortunately, only a small number of studies has investigated the effects of BACs below 0.05%. It is noteworthy that the studies in this table are all of recent origin, with only 6 of the 24 entries published before 1975 and none prior to 1970. Visual backward masking tasks are common in this area, with 5 studies reporting data from this type of task.

A series of studies by Moskowitz and collegues has examined alcohol effects on information processing, using a variety of measures. Moskowitz and Burns (1971) studied alcohol effects on the psychological refractory period, a measure of central information processing time; they found that alcohol produced an increase in the time required for central processing. Moskowitz and Roth (1971) studied the time required to name an object presented in the visual field, and found that low doses of alcohol substantially increased the time needed for information processing. Moskowitz and Murray (1976) used a backward masking technique and found that computed BACs of 0.05% or more substantially increased the time required for processing visual images from iconic memory into short-term storage. Moskowitz and Keller (1979) explored alcohol effects on rate of switching of attention, and found significant impairment at reported BACs of 0.05%.

TABLE 6

SUMMARY OF FINDINGS FOR DIVIDED ATTENTION PERFORMANCE

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Hamilton & Copeman (1970)	*Pursuit tracking under noise *Detection of peripheral stimuli under both noise and quiet
0.02		Moskowitz & Shea (1971)	*Tone detection *Digit recall
0.03		Gruner (1955)	Digit cancelling Visual reaction time
0.03		Gruner et al. (1964)	Digit cancelling Visual reaction time
0.04		Connors & Maisto (1980)	*Pursuit tracking Choice reaction time
0.04		Mills & Bisgrove (1983)	Response to central stimuli Response to peripheral stimuli
0.05	#	Mills & Bisgrove (1983)	Response to central stimuli Response to peripheral stimuli
0.05		Moskowitz & Burns (1981)	*Compensatory tracking *Visual search
0.05		Moskowitz & Sharma (1974)	*Counting central visual stimuli *Detection of peripheral light
0.05		Vuchinich & Sobell (1978)	*Pursuit tracking Choice reaction time
0.06		Moskowitz & DePry (1968)	*Tone detection *Digit recall
0.06		Von Wright & Mikkonen (1970)	*Signal detection *Compensatory tracking

TABLE 6 (Contd.)

0.07		Burns & Moskowitz (1980)	*Compensatory tracking *Visual search and recognition
0.07		Burns & Moskowitz (1981)	*Compensatory tracking *Visual search and recognition
0.07	#	Moskowitz & Burns (1981)	*Compensatory tracking *Visual search and recognition
0.08	#	Hamilton & Copeman	*Pursuit tracking *Detection of peripheral stimuli
0.09	#	Mills & Bisgrove (1983)	Response to central stimuli Response to peripheral stimuli
0.10	#	Mills & Bisgrove (1983)	Response to central stimuli Response to peripheral stimuli
0.10		Moskowitz (1971)	*Compensatory tracking (simulator) *Reaction time to peripheral lights
0.11		Chiles & Jennings (1970)	*Compensatory tracking
0.11	#	Mills & Bisgrove (1983)	Response to central stimuli Response to peripheral stimuli
0.11	#	Moskowitz & Sharma (1974)	*Counting central visual stimuli *Detection of peripheral lights *Meter monitoring
0.11	#	Von Wright & Mikkonen (1970)	*Signal detection Compensatory tracking

TABLE 6 (Contd.)

0.12	#	Moskowitz & Burns (1981)	*Compensatory tracking *Visual search and recognition

NUMBER OF ENTRIES IN THIS TABLE: 24 (15 studies)

# indicates a repeated citation.
* indicates that the study specifically reported impairment of this task component, rather than solely the combined tasks of the divided-attention task.

FIGURE 9
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON DIVIDED ATTENTION

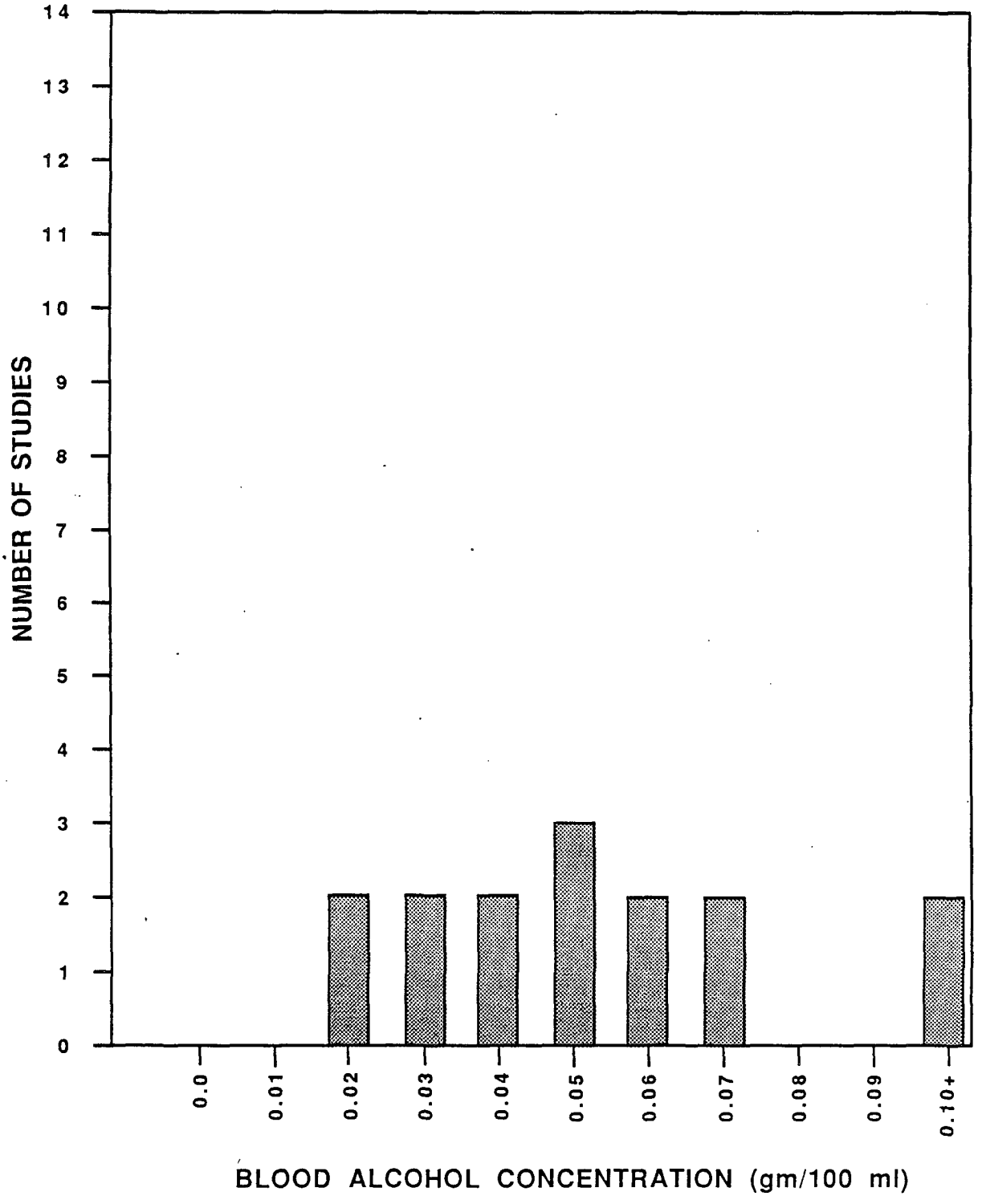


TABLE 7

SUMMARY OF FINDINGS FOR INFORMATION PROCESSING

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Moskowitz et al. (1985)	Visual backward masking
0.03	#	Moskowitz et al. (1985)	Visual backward masking
0.04		Moskowitz & Murray (1976)	Visual backward masking
0.04	#	Moskowitz et al. (1985)	Visual backward masking
0.05		Attwood (1978)	Interpretation of signals
0.05		Kostandov et al. (1982)	Visual backward masking
0.06		MacArthur & Sekuler (1982)	Visual information processing
0.06		Mills & Ewing (1977)	Memory comparison
0.06		Moskowitz & Roth (1971)	Response latency
0.06	#	Moskowitz et al. (1985)	Visual backward masking
0.07		Burns & Moskowitz (1980)	Visual backward masking
0.07		Kobayashi (1975)	Information processing rate
0.07		Moskowitz & Burns (1981)	Information processing rate
0.07		Moskowitz et al. (1976)	Visual search Eye dwell duration
0.07		Oborne & Rogers (1983)	Reaction time
0.07		Parker et al. (1974)	Information registration, recall, and organization
0.07		Vogel-Sprott (1976)	Coding performance
0.07		Zunder (1977)	Response selection
0.08	#	Attwood (1978)	Interpretation of signals

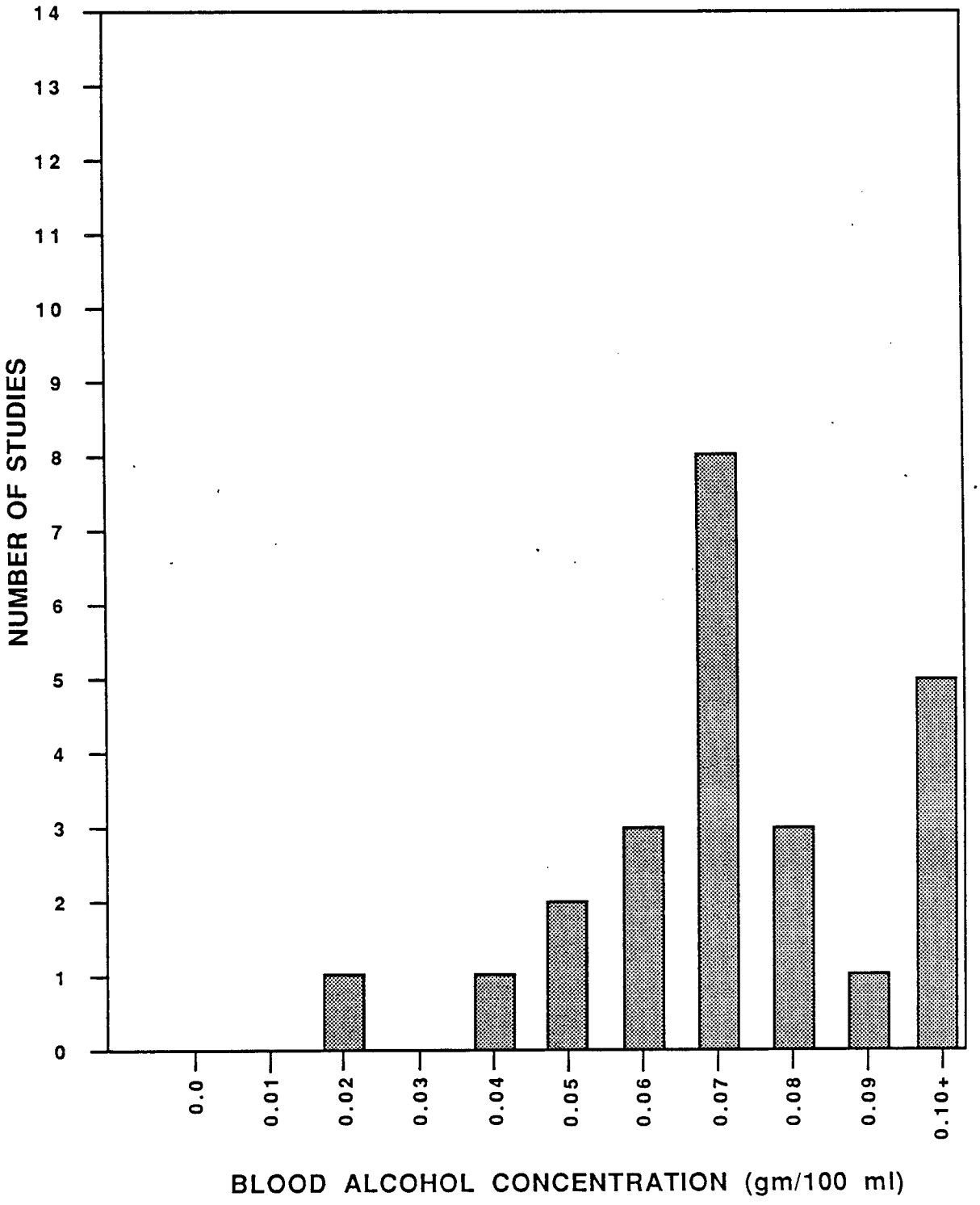
TABLE 7 (Contd.)

0.08		Fitzpatrick & Eviatar (1980)	Speech discrimination
0.08		Moskowitz & Burns (1973)	Naming visual stimuli
0.08	#	Oborne & Rogers (1983)	Reaction time
0.08		Williams & Rundell (1984)	Verbal recognition and recall
0.09		Moskowitz & Burns (1971)	Psychological refractory period
0.10	#	Kostandov et al. (1982)	Visual backward masking
0.10	#	Moskowitz & Murray (1976)	Visual backward masking
0.11		Chiles & Jennings (1970)	Meter monitoring
0.11		Moskowitz & Burns (1976)	Visual backward masking, response latency
0.12	#	Moskowitz & Burns (1981)	Information processing rate
0.13	#	MacArthur & Sekuler (1982)	Visual information processing
0.13		Tharp et al. (1974)	Character recognition
0.13	#	Williams & Rundell (1984)	Verbal recognition and recall
0.14	#	Parker et al. (1974)	Information registration, recall, and organization
0.15	#	Moskowitz et al. (1976)	Visual search Eye dwell duration
0.15	#	Zunder (1977)	Response selection
0.18		King (1975)	Speed of initiating motor responses
0.18		Rosen & Lee (1976)	Information storage, recall, and organization

NUMBER OF ENTRIES IN THIS TABLE: 37 (24 studies)

# indicates a repeated citation.

FIGURE 10
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON INFORMATION PROCESSING



This series of experiments indicates that central information processing suffers significant degradation at BACs of 0.05% or more, a conclusion supported by the trends presented in Table 7 and Figure 10.

OPTOMETRIC VISUAL FUNCTIONS

Table 8 presents the reviewed findings on optometric visual functions indicating the BACs at which impairment has been found. These findings are summarized in Figure 11. The term "optometric visual function" refers to those visual functions most likely to be tested by an optometrist or opthalmologist, in contrast to studies of visual performance where more complex central processing of information is involved. Studies of this latter type of visual performance will be discussed with other sensory modalities under the heading of perception, and some have also been discussed in the sections on information processing.

It is clear that these headings are somewhat arbitrary, especially from the point of view of a reviewer who is making a judgement regarding the behavioral area under which another experimenter's study should be placed. It is unlikely that all the studies of visual function reviewed in this section are primarily peripheral in nature, with little central nervous system participation. However, it is the degree of involvement of central processing which is the basis of the assignment of the category into which the articles have been placed here. The difficulties involved in making these judgements can be seen from the very first article in Table 8, a study by Adams and Brown (1975) on glare recovery in which they found impairment at a BAC of 0.01%. Subsequently, a study performed in 1977 by Sekuler and MacArthur found no impairment due to glare at a BAC of 0.09%. Rather, Sekuler and MacArthur demonstrated that the Adams and Brown report of impairment was due to the effect of alcohol on the subjects' ability to acquire the brightness comparison target used as a measure of glare recovery rather than the direct effect of alcohol on glare recovery. Thus, what was purported to be a study of glare recovery now turns out to be a study of visual search, a more complex process which should be considered under the heading of perception. Since the authors, Adams and Brown (1975), described it as a study in glare recovery, it has been retained in Table 8 as an example of the difficulty of isolating all the behavioral variables on which alcohol might act in a particular study. Certainly it remains a socially relevant fact that impairment occurred in the ability to see an object under glare conditions at a BAC of 0.01%, even if the fundamental biological nature of the impairment was not operating directly on the glare recovery process. Thus, it must be understood that the behavioral category described in the present tables and figures will undoubtedly contain studies which truly also belong in other behavioral areas. The present work has attempted to overcome this difficulty in the assignment of any particular study to the proper behavioral area by including such a large number of studies that an error with respect to any particular study would become less significant.

Twenty-eight studies were reviewed, of which 13 were reported in 1975 or later years. Twelve of the reviewed studies found impairment at BACs of 0.05% or less. Most of the studies reporting impairment at these low BACs were in the area of oculomotor control and dealt with eye movement and fusion capacities. Other optometric areas presented less consistent results. For example, studies

TABLE 8

SUMMARY OF FINDINGS FOR OPTOMETRIC VISUAL FUNCTIONS

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.01		Adams & Brown (1975)	Glare recovery
0.03		Bjerver & Goldberg (1950)	Flicker fusion
0.03		Charnwood (1959)	Fusional reserves
0.03		Schroeder et al. (1974)	Frequency of eye movements Field of view
0.04	#	Charnwood (1959)	Fusional reserves
0.04		Wilson & Mitchell (1983)	Visual acuity for distance Convergence nearpoint
0.05	#	Adams & Brown (1975)	Glare recovery
0.05		Baloh et al. (1979)	Saccade maximum velocity and reaction time Smooth pursuit eye velocity Optokinetic slow component velocity
0.05	#	Bjerver & Goldberg (1950)	Blink test
0.05	#	Charnwood (1959)	Fusional reserves
0.05		Collins et al. (1971)	Nystagmic eye movements Slow phase eye velocity
0.05		Flom et al. (1976)	Saccadic movements Smooth pursuit tracking
0.05		Fregly et al. (1967)	Nystagmatic eye movements
0.05		Guedry et al. (1975)	Smooth oculomotor tracking Vestibular nystagmus
0.05		Hazlett & Allen (1968)	Contrast sensitivity Visibility distances

TABLE 8 (Contd.)

0.05	#	Wilson & Mitchell (1983)	Visual acuity for distance Convergence nearpoint
0.06	#	Charnwood (1959)	Fusional reserves
0.06		Mortimer (1963)	Visual acuity
0.06	#	Wilson & Mitchell (1983)	Visual acuity for distance Convergence nearpoint
0.07	#	Collins et al. (1971)	Nystagmic eye movements Slow phase eye velocity
0.07		Damkot & Frysinger (1978)	Stimulus detection thresholds
0.07	#	Fregly et al. (1967)	Nystagmatic eye movements
0.07		Kobayashi (1975)	Fixation duration Saccadic eye movements Horizontal eye movements
0.07		Laplasse (1965)	Resistance to glare
0.07		Verriest & Laplasse (1965)	Resistance to glare
0.08		Adams et al. (1975)	Dynamic visual acuity
0.08	#	Fregly et al. (1967)	Nystagmatic eye movements
0.08	#	Guedry et al. (1975)	Smooth oculomotor tracking Vestibular nystagmus
0.08		Newman & Fletcher (1941)	Visual acuity Depth perception Distance judgement Eye coordination Glare resistance and recovery Side vision
0.08		Welch et al. (1977)	Sensitivity to oculogyral illusion
0.09		Erwin et al. (1978)	Missed signals due to blinking
0.09	#	Fregly et al. (1967)	Nystagmatic eye movements
0.09		McNamee et al. (1981)	Distance vision

TABLE 8 (Contd.)

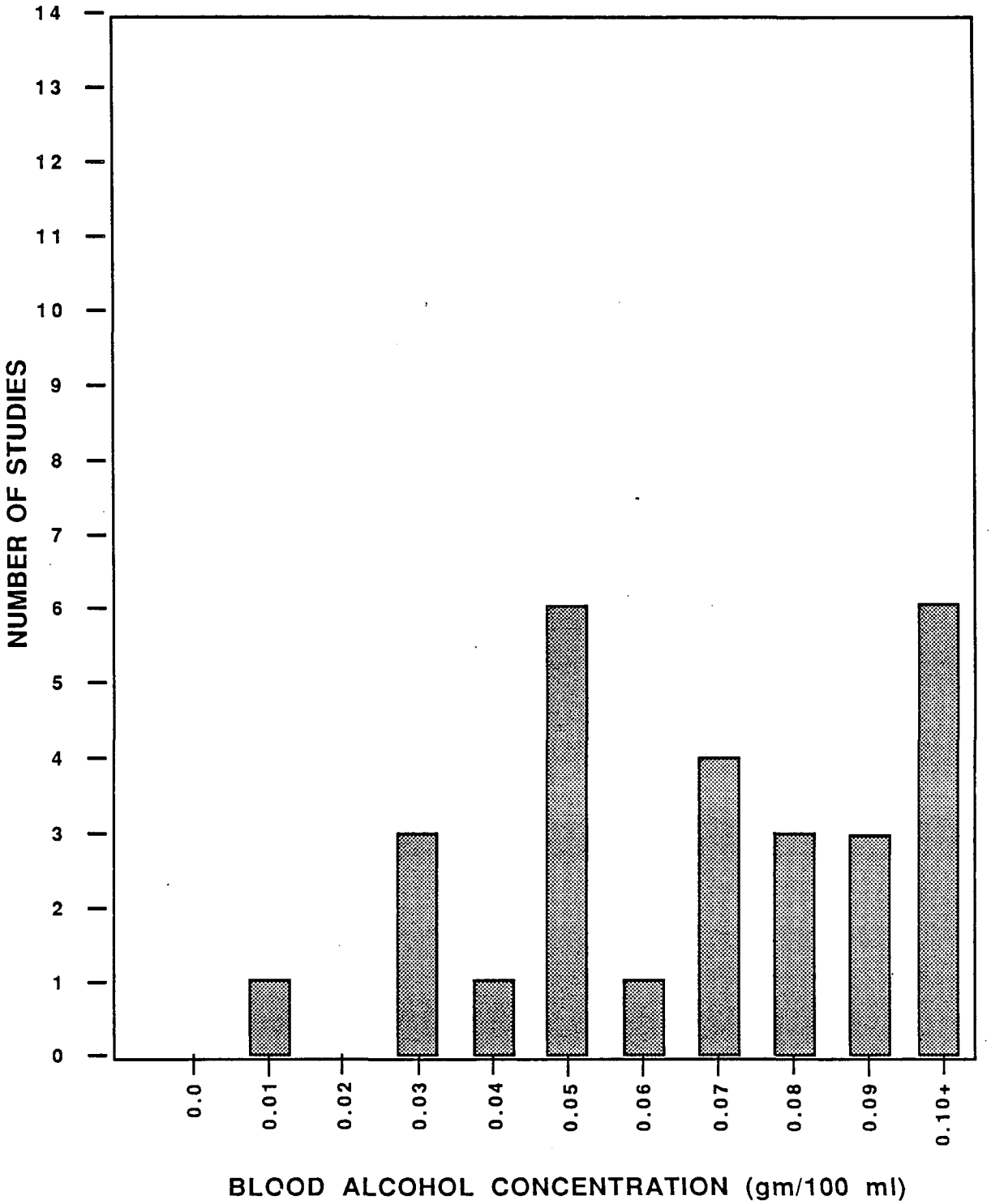
0.09		Moskowitz & Ziedman (1979)	Fixation duration Pursuit durations Time to read signs
0.10	#	Baloh et al. (1979)	Saccade maximum velocity and reaction time Smooth pursuit eye velocity Optokinetic slow component velocity
0.10		Brecher et al. (1955)	Fusion time
0.10	#	Flom et al. (1976)	Saccadic movements Smooth pursuit tracking
0.10		Franks (1964)	Spontaneous blink rate Fluctuation of perspective
0.10		Hogman et al. (1977)	Re-adaptation after glare
0.10		Sekuler & MacArthur (1977)	Glare recovery Target localization after glare
0.11		Lewis et al. (1969)	Flicker fusion Spiral after effect
0.11	#	Newman & Fletcher (1941)	Visual acuity Depth perception Distance judgement Eye coordination Glare resistance and recovery Side vision
0.13	#	Moskowitz & Ziedman (1979)	Fixation duration Pursuit durations
0.13		Zuzewicz (1981)	Latency of visual evoked potential
0.14	#	Damkot & Frysinger (1978)	Stimulus detection thresholds
0.14	#	Erwin et al. (1978)	Missed signals due to blinking
0.15	#	Brecher et al. (1955)	Fusion time

TABLE 8 (Contd.)

0.15	#	Newman & Fletcher (1941)	Visual acuity Depth perception Distance judgement Eye coordination Glare resistance and recovery Side vision
NUMBER OF ENTRIES IN THIS TABLE: 48			(28 studies)

# indicates a repeated citation.

FIGURE 11
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON VISUAL FUNCTION



of alcohol effects on glare recovery have produced mixed results. Mortimer (1963) studied day and night driving in a simulator and found that at reported BACs of 0.01% tracking was likely to be affected by night glare conditions, but glare recovery was unaffected by BACs ranging from 0.01 to 0.06%. On the other hand, as noted above, Adams and Brown (1975) reported increased glare recovery time at a BAC of 0.01%. This result, in turn, was contradicted by Sekuler and MacArthur (1977) who replicated Adams and Brown's study with larger brightness comparison targets and found no impairment of glare recovery at BACs of 0.09%. Moskowitz et al. (1972) similarly found no significant alcohol effects on glare recovery, and they also found no impairment of visual acuity or peripheral vision at computed BACs of 0.09%, a result which agrees with much of the experimental literature. The only impairment found by Moskowitz et al. at BACs of 0.09% was in the area of oculomotor control.

As noted above, there is considerable evidence that many visual oculomotor functions are impaired by relatively low doses of alcohol. Guedry et al. (1975) found that computed BACs of 0.05% produced significant impairment of visual suppression of vestibular nystagmus. Impairment was also found in visual tracking with alcohol reducing the amplitude of eye movement and producing a replacement of smooth ocular tracking with abbreviated saccades. Flom et al. (1976) found that computed BACs of 0.05% produced reductions in smooth tracking performance. They concluded that pursuit tracking was more sensitive to alcohol impairment than saccadic movements. However, higher BACs produced a decrease in the velocity of saccadic movements and increased latency time for initiating movement. Baloh et al. (1979) also found impairment of smooth pursuit eye movements, latency, response time, and maximum velocity of saccade movements, and the impairment of the slow component velocity in optokinetic nystagmus at BACs as low as 0.05%.

In summary, the evidence suggests that low or moderate doses of alcohol do not produce impairment of such visual functions as acuity, darkness adaptation, flicker fusion, or peripheral vision. A review by Hill et al. (1973) of seven studies of alcohol effects on critical flicker fusion thresholds indicated that findings were inconsistent, even allowing for variations in dosages. In contrast, however, aspects of oculomotor control have been impaired at BACs as low as 0.01% or 0.02%.

It should be noted that dynamic visual acuity has been listed as an optometric function, although it is likely that the tracking task involved is susceptible to alcohol impairment not only because of alcohol effects on oculomotor functioning but also because of alcohol effects on the central processing involved in the acquisition of the target.

Many of the areas which have been described here as relatively insensitive to impairment by alcohol will show show functional impairment in situations where the task involves great demand for information processing. For example, in the study by Moskowitz and Sharma (1974) which demonstrated that BACs up to 0.09% had no impairment effect on peripheral vision, the same measure of peripheral vision was highly impaired by computed BACs of 0.06% when the peripheral visual task had to be combined with a task occupying central vision and requiring information processing. Thus the alcohol impairment was due to the necessity for dual task performance, but the impairment appeared as in peripheral vision. This evidence is consistent with suggestions in the literature that alcohol produces "tunnel vision," or a narrowing of focus which can be significant for driving.

There has been considerable debate in the literature on the mechanism of alcohol effects on visual function. Studies of alcohol effects on fixation, such as those reported by Charnwood (1950) and Brecher et al. (1955) have suggested that alcohol impairs the general muscular coordination required for binocular vision. Studies of nystagmus (for example, Guedry et al., 1975) have suggested that alcohol reduces the capacity to override reflexive vestibular control of eye movements. Recent studies of visual evoked potentials under alcohol (for example, Zuzewicz, 1981) suggest a phasic effect on the central nervous system, with initial alcohol effects producing increased excitability of the CNS and later a depression of CNS activity.

PERCEPTION

Table 9 lists studies on perception at the BAC levels at which impairment was found. Figure 12 summarizes these results. The 22 studies in Table 9 date, in most cases, from the late 1970s or later. As noted previously, the placement of studies in this section, particularly those involving visual perceptual issues, is somewhat arbitrary. These studies appear to involve more complex central information processing behavior than the studies listed in Table 8. Among the studies examined here, there are several dealing with the distribution in space of eye fixations and with the duration of fixation. Both functions have been shown to be determined by decision processes within the subject, the latter particularly being a function of the duration necessary to process the information in the fixation. It is noteworthy that 10 of the studies included in Table 9 were also included in other tables.

Belt (1969), in a study using eye movement recordings in an actual car on the road, reported that BACs as low as 0.04% could produce changes in the distribution of eye fixation with an increased concentration in a smaller central visual field. Schroeder et al. (1974) produced similar results at reported BACs of 0.07%. Buikhuisen and Jongman (1972) examined eye movements in a driving simulator task and also found that reported BACs of 0.08% produced concentration of fixations in the central visual field, whereas subjects who had not consumed alcohol more frequently fixated objects in the periphery. Buikhuisen and Jongman studied eye movements in simulated traffic situations, and found that at BACs of 0.08% subjects concentrated on the central visual field and showed significant decrements in detection of objects in the peripheral field.

Finally, Kobayashi (1975) found that computed BACs of 0.07% led to increased frequencies of fixation in the bottom of the central visual field, and decreased frequencies of fixation in other areas. This finding, which has also been reported by other workers, indicates that the preview distance while driving will decrease. Kobayashi also reported a decrease in the number of horizontal eye movements as a result of alcohol.

Another area of frequent investigation has concentrated on the effects of alcohol on peripheral vision. Moskowitz and Sharma (1974) reviewed the optometric literature with respect to peripheral vision and reported that studies of peripheral vision, when examined in situations with no requirement for any other behavioral demands, indicated no effects of alcohol. However, a series of studies found impairment of peripheral vision at very low BACs when the central visual field was occupied with a task requiring considerable

TABLE 9

SUMMARY OF FINDINGS FOR PERCEPTION

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Adams & Brown (1975)	Recovery from glare
0.02		MacArthur & Sekuler (1982)	Reaction time to onset of motion
0.04		Moskowitz & Sharma (1974)	Peripheral vision with a central task
0.04		Sidell & Pless (1971)	Time perception
0.05		Kostandov et al. (1982)	Time to perceive visual stimuli
0.06	#	MacArthur & Sekuler (1982)	Reaction time to onset of motion
0.07		Fitzpatrick & Eviatar (1980)	Speech discrimination
0.07		Moskowitz et al. (1976)	Dwell duration and frequency Pursuit duration and frequency Visual search behavior
0.07		Pfefferbaum et al. (1979)	Auditory evoked potentials
0.07		Schneider & Carpenter (1969)	Auditory signal detectability
0.08	#	Adams & Brown (1975)	Recovery from glare
0.08		Bates (1981)	Visual movement sensitivity
0.08		Buikhuisen & Jongman (1972)	Perception of traffic incidents
0.08		Chandler & Parsons (1977)	Visual search performance
0.08		Tyson & Gavard (1976)	Auditory localization

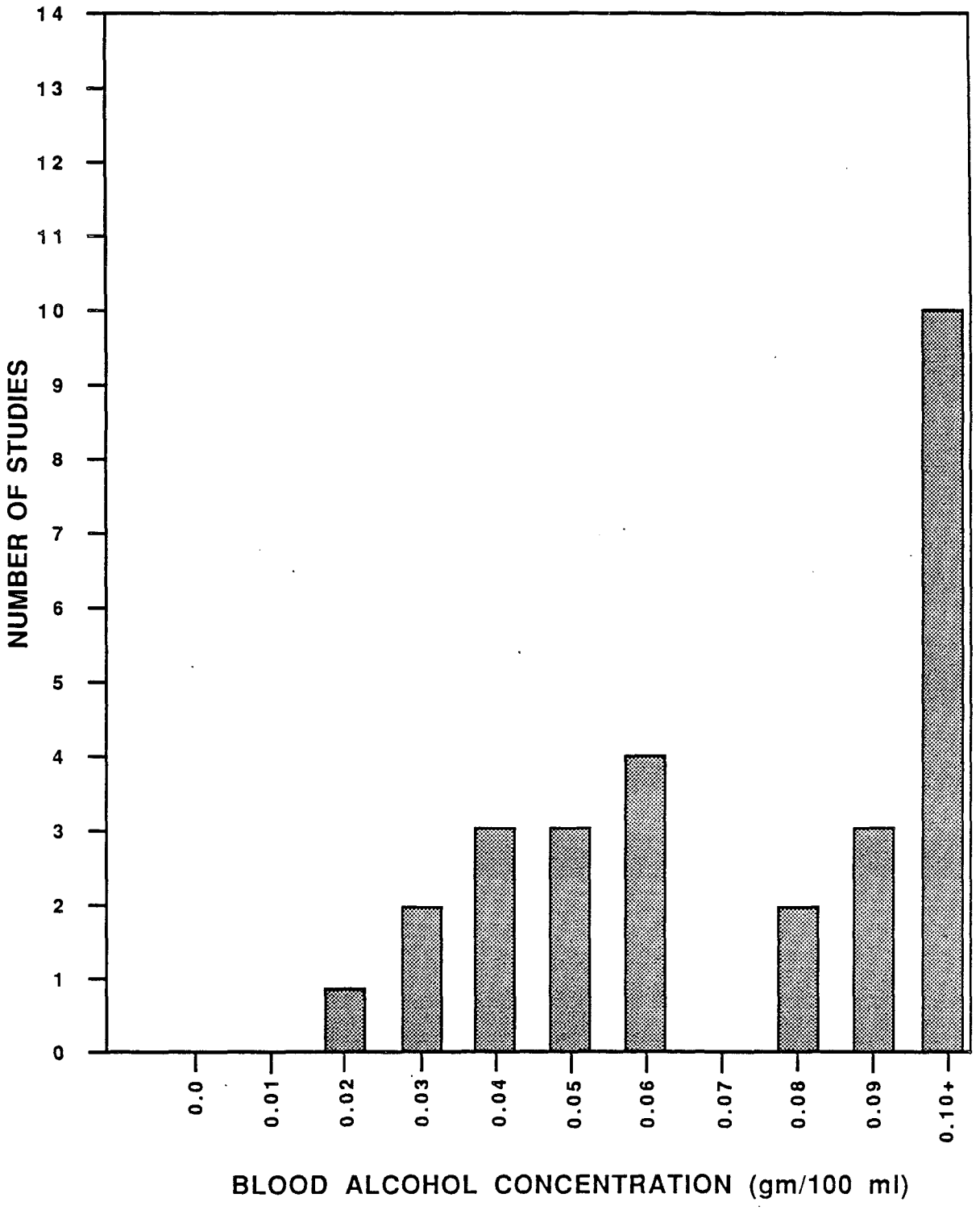
TABLE 9 (Contd.)

0.09		Chandler & Parsons (1975)	Visual search performance
0.09		Kristofferson (1968)	Perceptual field dependence
0.09		MacCarthy & Tong (1980)	Discrimination of velocities
0.10	#	Kostandov et al. (1982)	Time to perceive visual stimuli
0.10		Lewis et al. (1969)	Spiral after-effect
0.10	#	Moskowitz & Sharma (1974)	Peripheral vision with a central task
0.10	#	Schneider & Carpenter (1969)	Auditory signal detectability
0.10		Sekuler & MacArthur (1977)	Glare recovery Target localization after glare
0.10	#	Sidell & Pless (1971)	Time perception
0.10		Tinkleberg et al. (1976)	Time perception
0.13		Moskowitz & Ziedman (1979)	Time taken to read signs
0.13		Tharp et al. (1974)	Character recognition
0.14	#	Moskowitz et al. (1976)	Dwell duration and frequency Pursuit duration and frequency Visual search behavior
0.14	#	Sidell & Pless (1971)	Time perception
0.15	#	Lewis et al. (1969)	Spiral after-effect
0.15		Wait et al. (1982)	Proprioception
0.16	#	Wait et al. (1982)	Proprioception
0.17	#	Sidell & Pless (1971)	Time perception
0.20	#	Sidell & Pless (1971)	Time perception

NUMBER OF ENTRIES IN THIS TABLE: 34 (22 studies)

# indicates a repeated citation.

FIGURE 12
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON PSYCHOMOTOR PERFORMANCE



information processing. Thus Hamilton and Copeman (1970), using a central tracking task combined with a peripheral visual light detection task, found significant deterioration of the peripheral detection task at reported BACs beginning at 0.017%. Von Wright and Mikkonen (1970) also combined a central vision tracking task with a peripheral vision signal detection task and found impairment at reported BACs of 0.05% and above.

Huntley (1970) combined a peripheral visual recognition task with a central visual information processing task and found that BACs of 0.08% and above produced impairment of the time required to recognize and respond to the visual stimuli. Finally, Moskowitz and Sharma (1974) found impairment of peripheral vision at BACs below 0.05% when a central visual task required information processing. As mentioned in the preceding section, no impairment was found when the central visual stimulus did not require information processing.

It should be noted that the study by Adams and Brown (1975), which found impairment of glare recovery at BACs of 0.01%, is included in Table 9 as well as in the preceding table. This study is included in Table 9 because, based on the work of Sekuler and MacArthur (1977), it appears that the impairment was really in target acquisition, which is clearly a perceptual function. It was included in Table 8 because the experimenters considered that the impairment was in an aspect of visual function.

While the majority of studies in Table 9 did not report impairment until BACs of 0.08%, there were five studies which found perceptual impairment at BACs of 0.05% or less. Several of the studies in this section have attempted to determine the central nervous system locus of alcohol induced impairment, particularly with respect to whether the impairment is more likely to be in the left or right hemisphere.

Chandler and Parsons (1975) have found evidence that reported BACs of 0.075% to 0.080% slowed visual search times, with longer search times for shapes presented to the left visual area on the ascending limb of the BAC curve (reported BACs of 0.077 - 0.080%), and for shapes presented to the right visual area on the descending limb of the BAC curve (reported BACs of 0.085%). Verbal stimuli showed no alcohol effects, so it was concluded that alcohol selectively impairs right hemisphere processing with only minimal effects on left hemisphere processing. Chandler and Parsons (1977) have found further confirmation of this effect, and also indications that alcohol produces changes in normal laterality functions, suggesting that left hemisphere processing may also be affected, with these effects evident only in retrieval of information. Using a backward masking technique, Kostandov et al. (1982) have also found that BACs of 0.05% and 0.10% impair right hemisphere functioning more than left hemisphere functions. These results suggest that right hemisphere functioning has a lower threshold for disruption than left hemisphere operations.

PSYCHOMOTOR PERFORMANCE

Many alcohol studies have employed tasks described as measures of psychomotor performance, where the response measures have in fact been based on reaction time or tracking tasks. In the present review such studies have been

incorporated in one or more of the appropriate sections above. Thus, this section includes only those studies of skilled performance which could not be considered relevant to one of the preceding sections, but which could be relevant to driving. However, some of the studies included in Table 10 investigated alcohol effects on a number of tasks, and thus nine studies were also included in other tables. Some of the studies reviewed in this section had limited relevance to driving performance, and the authors tended to include studies where there was possible, if uncertain, relevance for driving. Thus, for example, the study by Gregson et al. (1978) on walking performance was included here because it included aspects of coordination, and it is also of interest because of its possible relation to widely used tests of sobriety.

Table 10 shows the distribution of findings on psychomotor performance. Tasks presented here include standing steadiness measures, various coordination measures, and speed and accuracy tasks. A total of 28 studies is included here, with nine reporting impairment at or below BACs of 0.05%.

The diversity of tasks presented here makes difficult the drawing of detailed conclusions, but it can be suggested that BACs of 0.05% or more impair tasks which require skilled motor performance and coordination. The threshold of impairment may be a function of the difficulty of the task, with tasks which require high levels of movement precision likely to be impaired at lower BACs. Most of the tasks considered in previous sections require precise coordination, and evidence of alcohol impairment of these skills is consistent with this threshold of BAC effects.

The evidence suggests that standing steadiness is impaired by BACs below 0.05%, and this task is clearly not a skilled movement task. It has been suggested that alcohol effects on standing steadiness are a consequence of impairment of vestibulospinal reflexes, and results reported by Peiterson (1966) have indicated that such impairment can be produced by BACs of 0.04% or more. In any case, the low threshold for steadiness impairment may account for its popularity as a sobriety test among law enforcement agencies.

DRIVER PERFORMANCE

Table 11 shows the reviewed findings on driver performance; these results are summarized in Figure 13. Two types of research settings were found in these studies: the laboratory driving simulator, and actual on-road driving tests. These contexts are identified in the table by the letters **S** (for **s**imulator studies) and **R** (for on **r**oad tests) under the heading "task type." Driver performance studies are characterized by the large number of different measures which are possible in both of these settings. The task names shown in the table are based on those provided by the authors in each case (with some abbreviation due to space considerations), and no attempt has been made to convert these descriptions to standardized names; for details of the tasks used, the reader is referred to the cited works.

Table 11 includes 41 significant findings of alcohol effects on driver performance, with 27 of these findings resulting from simulator studies. Eight studies showed performance decrements at BACs of 0.05% or less, and a further five studies found impairment at BACs of 0.06 to 0.08%. Eight of the studies were reported in 1975 or later.

TABLE 10

SUMMARY OF FINDINGS FOR PSYCHOMOTOR PERFORMANCE

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.02		Idestrom & Cadenius (1968)	Coordination
0.03	#	Idestrom & Cadenius (1968)	Coordination
0.03		Price & Hicks (1979)	Manual assembly
0.03		Saario et al. (1975)	Eye-hand coordination
0.04		Evans et al. (1974)	Standing steadiness
0.04		Franks et al. (1976)	Standing steadiness
0.04	#	Idestrom & Cadenius (1968)	Coordination
0.04		Sidell & Pless (1971)	Coordination
0.05		Connors & Maisto (1980)	Motor performance
0.05	#	Evans et al. (1974)	Standing steadiness
0.05	#	Idestrom & Cadenius (1968)	Coordination
0.05		Lewis (1973)	Visual motor coordination
0.05		Price & Flax (1982)	Drill press operation
0.05	#	Saario et al. (1975)	Eye-hand coordination
0.06		Cappell et al. (1972)	Timing keypress responses
0.06	#	Connors & Maisto (1980)	Motor performance
0.06	#	Franks et al. (1976)	Standing steadiness
0.06		Hurst & Bagley (1972)	Standing steadiness
0.06	#	Idestrom & Cadenius (1968)	Coordination Standing steadiness
0.06		Lindenschmidt et al. (1983)	Purdue pegboard
0.06		Morland et al. (1974)	Mirror tracing Coordination
0.06	#	Saario et al. (1975)	Eye-hand coordination

TABLE 10 (Contd.)

0.07	#	Evans et al. (1974)	Standing steadiness
0.07	#	Franks et al. (1976)	Standing steadiness
0.07	#	Hurst & Bagley (1972)	Standing steadiness
0.07	#	Idestrom & Cadenius (1968)	Coordination Standing steadiness
0.08		Consroe et al. (1979)	Finger tapping
0.08	#	Franks et al. (1976)	Standing steadiness
0.08		Woollacott (1983)	Sway adjustment anterior/posterior lateral
0.09	#	Cappell et al. (1972)	Timing keypress responses
0.09	#	Evans et al. (1974)	Standing steadiness
0.09	#	Franks et al. (1976)	Standing steadiness
0.09		Hollister & Gillespie (1970)	Digit symbol test
0.09		Karhunen et al. (1978)	Coordination
0.09	#	Price & Hicks (1979)	Manual assembly
0.09		Wilson et al. (1970)	Digit symbol test Hand steadiness
0.10		Bird et al. (1982)	Standing steadiness
0.10	#	Consroe et al. (1979)	Finger tapping
0.10	#	Franks et al. (1976)	Standing steadiness
0.10	#	Hollister & Gillespie (1970)	Digit symbol test
0.10	#	Karhunen et al. (1978)	Coordination
0.10	#	Price & Flax (1982)	Drill press operation
0.10	#	Sidell & Pless (1971)	Coordination
0.11	#	Karhunen et al. (1978)	Coordination
0.11		Tarter et al. (1971)	Purdue pegboard
0.12	#	Cappell et al. (1972)	Timing keypress responses
0.12	#	Consroe et al. (1979)	Finger tapping
0.12	#	Bird et al. (1982)	Standing steadiness
0.12		Reisby & Theilgaard (1966)	Motor coordination
0.12		Tripp et al. (1959)	Handwriting
0.13	#	Consroe et al. (1979)	Finger tapping

TABLE 10 (Contd.)

0.13		Gregson et al. (1978)	Walking performance
0.13		Nuotto et al. (1982)	Coordination Manual dexterity Standing steadiness
0.13		Nuotto et al. (1984)	Coordination Body balance
0.13		Palva et al. (1979)	Coordination
0.14	#	Consroe et al. (1979)	Finger tapping
0.14	#	Palva et al. (1979)	Coordination
0.14	#	Sidell & Pless (1971)	Coordination
0.15	#	Consroe et al. (1979)	Finger tapping
0.16	#	Consroe et al. (1979)	Finger tapping
0.16	#	Gregson et al. (1978)	Walking performance
0.16	#	Lewis (1973)	Visual motor coordination
0.16		Wait et al. (1982)	Mirror tracing
0.17	#	Sidell & Pless (1971)	Coordination
0.20		Linnoila et al. (1981)	Coordination Standing steadiness
0.20	#	Nuotto et al. (1982)	Coordination Manual dexterity Standing steadiness
0.20	#	Nuotto et al. (1984)	Coordination Body balance
0.21	#	Sidell & Pless (1971)	Coordination

NUMBER OF ENTRIES IN THIS TABLE: 68 (28 studies)

# indicates a repeated citation.

TABLE 11

SUMMARY OF FINDINGS FOR DRIVER PERFORMANCE

BAC AT WHICH IMPAIRMENT FOUND		AUTHOR(S)/YEAR	TASK TYPE	TASK(S) FOR WHICH IMPAIRMENT FOUND
0.03		Bragg & Wilson (1980)	R	Vehicle alignment Speed on centerline
0.03		Drew et al. (1959)	S	Tracking Steering Gear changing Braking
0.03		Heacock & Wikle (1974)	S	Distance judgement
0.03		Mortimer (1963)	S	Tracking under glare
0.04		Coldwell et al. (1958)	R	Car handling
0.04	#	Drew et al. (1959)	S	Tracking Steering Gear changing Braking
0.04		Laurell (1977)	R	Emergency braking Evasive maneuvers
0.05		Bjerver & Goldberg (1950)	R	Garaging Parking Steering
0.06	#	Drew et al. (1959)	S	Tracking Steering Gear changing Braking
0.06		Smiley et al. (1975)	R	Stopping accuracy

TABLE 11 (Contd.)

0.07		Damkot (1981)	R	Accelerator reversals Speed changes
0.07	#	Heacock & Wikle (1974)	S	Distance judgement
0.07	#	Mortimer (1963)	S	Glare adaptation
0.07		Mortimer & Sturgis (1975a)	S	Tracking Lateral position error Time taken to apply steering correction
0.07		Mortimer & Sturgis (1975b)	S	Steering performance
0.08	#	Bragg & Wilson (1980)	R	Vehicle alignment Speed on centerline
0.08		Milner & Landauer (1971)	S	Driving errors Reaction time
0.08	#	Mortimer & Sturgis (1975b)	S	Steering
0.09		Attwood et al. (1981)	R	Car following Speed maintenance
0.09	#	Drew et al. (1959)	S	Tracking Steering Gear changing Braking
0.09		Kielholz et al. (1969)	R	Driving test performance Reaction time
0.09	#	Mortimer & Sturgis (1975a)	R	Headway, speed maintenance in car following
0.09		Sugarman et al. (1973)	S	Vehicle position Speed maintenance Reaction time
0.10		Landauer et al. (1974)	S	Steering

TABLE 11 (Contd.)

0.10	#	Mortimer & Sturgis (1975a)	S	Acceleration, headway in car following Response time to stop in car following
0.10		Rafaelson et al. (1973)	S	Braking time Gear changing
0.11		Attwood et al. (1980)	R	Car following Speed maintenance
0.11		Crancer et al. (1969)	S	Accelerator, braking
0.11	#	Damkot (1981)	R	Driving accuracy Accelerator reversals Speed changes Number of brake applications
0.11	#	Heacock & Wikle (1974)	S	Distance judgement
0.11	#	Mortimer & Sturgis (1975b)	S	Steering
0.11		Moskowitz (1971)	S	Tracking Reaction time to peripheral stimuli
0.12		Bech et al. (1973)	S	Time and distance estimation
0.12		Huntley & Centybear (1974)	R	Steering Accelerator use Rate of speed changes
0.12	#	Mortimer & Sturgis (1975b)	S	Steering
0.12	#	Sugarman et al. (1973)	S	Vehicle position Speed maintenance Reaction time

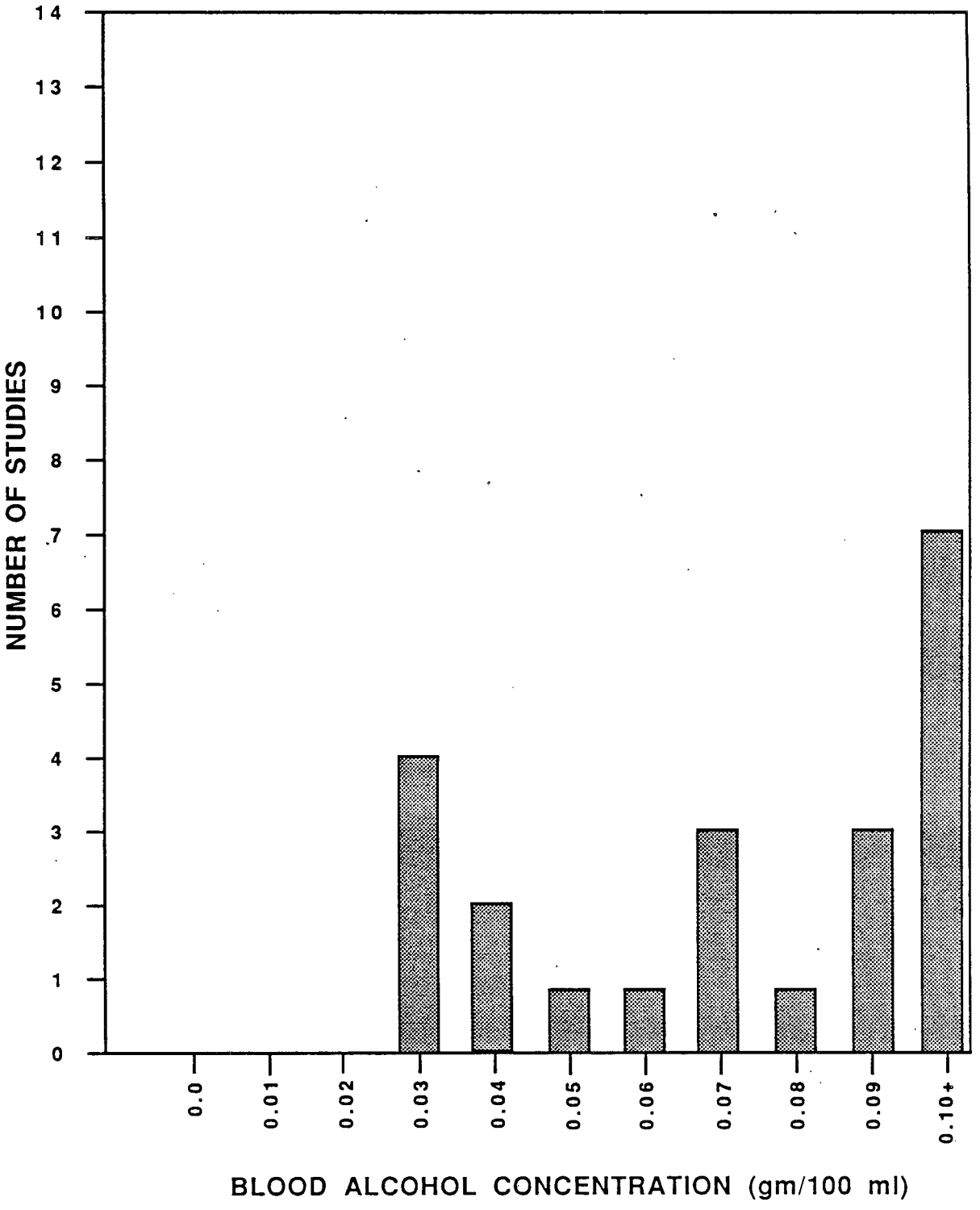
TABLE 11 (Contd.)

0.14	#	Crancer et al. (1969)	S	Accelerator, braking, signal errors
0.14	#	Mortimer & Sturgis (1975b)	S	Steering
0.15	#	Heacock & Wikle (1974)	S	Distance judgement
0.16	#	Crancer et al. (1969)	S	Accelerator, speed, signal errors

NUMBER OF ENTRIES IN THIS TABLE: 40 (22 studies)

# indicates a repeated citation.
R indicates road tests.
S indicates simulator studies.

FIGURE 13
NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON DRIVING PERFORMANCE



Heimstra and Struckman (1972) and Moskowitz (1975) have noted that data from driving simulator studies have been inconsistent, and even contradictory at times. Moskowitz (1975) has suggested that comparisons between simulator studies are difficult due to the fact that available simulators differ greatly in the demands they place on subjects, and that variable results would be expected as a consequence. Even so, Moskowitz assessed evidence from simulator tasks as demonstrating that the information processing and time sharing aspects are most readily impaired by low to moderate doses of alcohol.

Moskowitz (1971) found impairment on a simulator task at BACs of 0.11%, but only when a subsidiary task was used; performance on the simulator alone was not affected. Allen et al. (1975) studied the effects of reported BACs of 0.06 and 0.11% on a simulator task and found increases in steering errors and increased detection and reaction times to a discrete visual search task. Performance of the steering task showed greater impairment when the discrete task was also present. Asknes (1954) used a Link flying trainer task and found significant impairment at reported BACs of 0.05% when the task required subjects to simultaneously "fly" the simulator, navigate, track a course, and monitor flight instruments.

Findings from some divided attention studies are relevant in interpreting these results. For example, Chiles and Jennings (1970) found alcohol effects on a tracking task only when it was accompanied by a subsidiary task, and concluded that the subjects' ability to time-share was the aspect of performance most affected by alcohol. Von Wright and Mikkonen (1970) found that BACs of 0.06% were sufficient to produce impairment of a combined tracking and visual search task. As noted in earlier sections, divided attention performance is impaired by relatively low BACs, and simulator studies such as those noted above which emphasize the importance of the divided attention or time sharing component of driving demonstrate impairment at low BACs. Subjects may compensate for effects of low to moderate BACs by increasing concentration or by speed-accuracy trade-offs when the demands of driving are artificially restricted in testing situations, but these strategies are unable to maintain performance of time shared tasks as found in real life situations.

Results here suggest that BACs as low as 0.03% can produce significant impairment of driver performance. BACs of 0.08% or less have been shown to impair accuracy of steering, braking, speed control, lane tracking, and gear changing, and also judgements of speed and distance in the driving situation. It is evident that BACs in this range are sufficient to impair ability to manipulate vehicle controls, and the capacity to respond to unexpected stimuli. Thus, it is important to note the findings of Laurell (1977) that computed BACs of 0.04% significantly impaired responses to unexpected, emergency situations, even in a simple driving situation. This finding, and the trends shown in Table 11 confirm the potential of low BACs to impair control capability, and reinforce the evidence noted above that alcohol increases the amount of attention required for the ongoing control of the vehicle, with deleterious consequences for the visual search and recognition aspects of the task.

OTHER FUNCTIONS AFFECTED BY ALCOHOL

The literature includes studies showing alcohol effects on a variety of other areas, including memory, problem solving performance, physical state and physiological functions, and aggression. These areas were considered to have less immediate relevance for driving; a brief review of findings in these areas is presented below.

Memory

Memory appears to be less directly related to driving than the areas discussed above. There is a vast literature demonstrating alcohol impairment of memory, particularly short-term memory. However, these impairments are unlikely to have safety consequences in most driving situations. In addition, evidence of memory impairment by alcohol is confounded by findings that state dependent learning can occur when an individual is intoxicated. Thus, studies such as those by Storm and Caird (1967) and Weingartner and Faillace (1971) have suggested that information learned during alcohol intoxication will be more readily recalled when the individual is intoxicated than when he is sober. There is some disagreement in the literature on the extent of this phenomenon, and Parker et al. (1976) have suggested that state dependent learning only occurs under alcohol intoxication when the task requires a substantial amount of information retrieval.

Studies of the effects of chronic alcoholism have found evidence of memory impairment although, as Goodwin and Hill (1972) have noted, these studies vary considerably in their experimental design and in their distinctions between immediate and short-term memory. Goodwin and Hill suggested that deficits in short-term memory are associated with alcoholic blackout, with this phenomenon occurring after a threshold point which is likely to represent moderate to high BACs. They concluded that alcoholic amnesia is substantially due to deficits produced in short-term memory.

Goodwin et al. (1970) studied the effects of reported BACs of 0.20 to 0.30% on remote, immediate, short-term, and recent memory, and found that only deficits in short-term memory were correlated with subsequent amnesiac effects. Ryback (1970) found short-term memory deficits associated with reported BACs of over 0.15%, and demonstrated that these deficits were correlated with subsequent failure to recall events during the period of intoxication. Lisman (1974) found that increases in BAC led to short-term memory deficits, but remote and immediate memory appeared to be unaffected.

Ryback (1971) has reviewed studies of alcohol effects on memory, and concluded that short-term memory is the area of memory function most likely to be affected by alcohol, with shortening of short-term memory span occurring with reported BACs of 0.10% and over. Jones (1973) reported similar conclusions, noting that immediate, short-term, and long-term memory were all affected by reported BACs of 0.09%, with short-term memory showing particularly sensitivity to alcohol induced deficits.

The literature is less consistent in its support for explanations of the memory mechanisms most affected by alcohol. Moskowitz and Murray (1976) have demonstrated that computed BACs of 0.04% do not impair the immediate memory

system. Perhaps memory deficits occur because alcohol increases the amount of information lost in the short-term store before it can be transferred to more resilient long-term storage. Tamerin et al. (1971) concluded that alcohol-induced short-term memory deficits are due to impairment of storage or retrieval mechanisms. Wickelgren (1975) and Parker et al. (1976) suggested that storage mechanisms are sensitive to alcohol impairmment, while Rosen and Lee (1976) and Gerrein and Chechile (1977) offered support for the notion that retrieval mechanisms are particularly affected by alcohol. Rosen and Lee (1976) reported evidence suggesting that alcohol impairs subjects' ability to effectively encode retrieval cues. Thus, the evidence in this area appears inconclusive in its assessment of which memory mechanisms are the locus of alcohol effects.

The available evidence indicates that memory is not sensitive to alcohol effects at low BACs and, even at higher BACs, it appears that only short-term memory function is affected. Moreover, it is not clear that all the above studies had adequate controls for possible alcohol impairment of information acquisition, as against alcohol effects on memory.

Problem Solving and Cognitive Tasks

In a review of the literature, Jellinek and McFarland (1940) concluded that BACs in the range 0.04 to 0.12% were sufficient to produce impairment of arithmetic tasks requiring addition of numbers. Significant alcohol effects on arithmetic task performance have also been reported by Frankenhaeuser et al (1962), Ekman et al. (1963, 1964), and Myrsten et al. (1980). Typically, BACs of 0.04 to 0.10% have been found to produce significant increases in numbers of errors, and also slowing of the rate of problem solving. Studies by Laties and Weiss (1962) and others have found that performance on time estimation tasks is also impaired by alcohol, with intoxicated subjects slower to decide estimates and more likely to underestimate. Lubin (1977, 1979) has reported alcohol impairment of digit substitution performance at BACs of 0.05 to 0.14%, and Consroe et al. (1979) have found impairment of symbol cancellation task performance at BACs of 0.07 to 0.16%. Further, there is evidence that the imposition of stress or distraction conditions in conjunction with alcohol increases the level of impairment. Thus Forney and Hughes (1964, 1965), Hughes et al. (1963), and Hughes et al. (1965) have combined alcohol with the use of delayed auditory feedback and found significantly increased levels of impairment.

This evidence suggests that BACs of 0.04% or more lead to decrements in problem solving performance, with increases in task difficulty, noise distraction or stress causing enhancement of the alcohol-induced impairment. The possibility exists that these impairments are again due to alcohol effects on information processing and multi-task processing loads.

Aggression

Theoretical considerations of aggression have suggested that alcohol may increase the tendency towards aggressive behavior. Laboratory studies of aggression have typically used experimental paradigms involving competitive

tasks where subjects could impose harm (such as an electric shock) on others. Shuntich and Taylor (1972) found that subjects were more likely to administer electric shocks in competitive situations and under the influence of computed BACs of 0.05% than they were in the absence of alcohol or competition. Taylor et al. (1976) explored the effects of computed BACs of 0.13% and concluded that alcohol-induced aggression was a function of both alcohol consumption and also the degree of threat perceived by the individual in the situation. Taylor et al. (1977) also found increases in aggression after alcohol, but found no evidence to support the prediction that frustration would increase the level of aggression.

Lang et al. (1975) have suggested that expectancies may affect the relation between alcohol and aggression. They found that subjects who believed that they had consumed alcohol were more aggressive than were those who believed that they had not consumed alcohol; no effects of actual alcohol dose were found.

These results offer some support for the proposition that alcohol increases the propensity for aggressive behavior. How these findings relate to driving is less clear. It is common to refer to some drivers as "aggressive" on the basis of their demonstrated driving styles, but there is little evidence on the effects of alcohol on the willingness to exhibit such behavior.

Physical State

Docter et al. (1966) have reported that BACs between 0.026% and 0.104% produced increases in heart rate and enhancement of Rapid Eye Movement activity; the lowest BACs (0.026%) induced marked increases in the amount of alpha wave activity in the electroencephalograph data for alcoholic subjects. Williams (1972) noted a lack of consistency in the available evidence of alcohol effects on heart rate and oxygen uptake. Using computed BACs of 0.02 and 0.04%, Williams found no evidence that either measure was affected by alcohol.

Some effects of alcohol on reflexes have been reported. Peiterson (1966) explored the effects of BACs of 0.04 and 0.08% on vestibulospinal reflexes, and found that both BACs impaired standing steadiness by increasing the amount of sideways body sway. As noted in the section on psychomotor performance (see above), alcohol effects on standing steadiness have been demonstrated by a number of investigators at BACs as low as 0.04%. Robinette and Brey (1978) found that BACs ranging from 0.09 to 0.15% reduced the magnitude of the protective acoustic reflex, and increased its threshold.

It is likely that the components of alcohol impairment of physical state which are relevant for driving are reflected in the previous sections of this report where they impact on the major components of driving skills. Relatively little evidence has been collected on the effects of alcohol on human physical performance, and some of the older studies in this area are of limited assistance in assessing the potential effects of alcohol or their importance for driver performance.

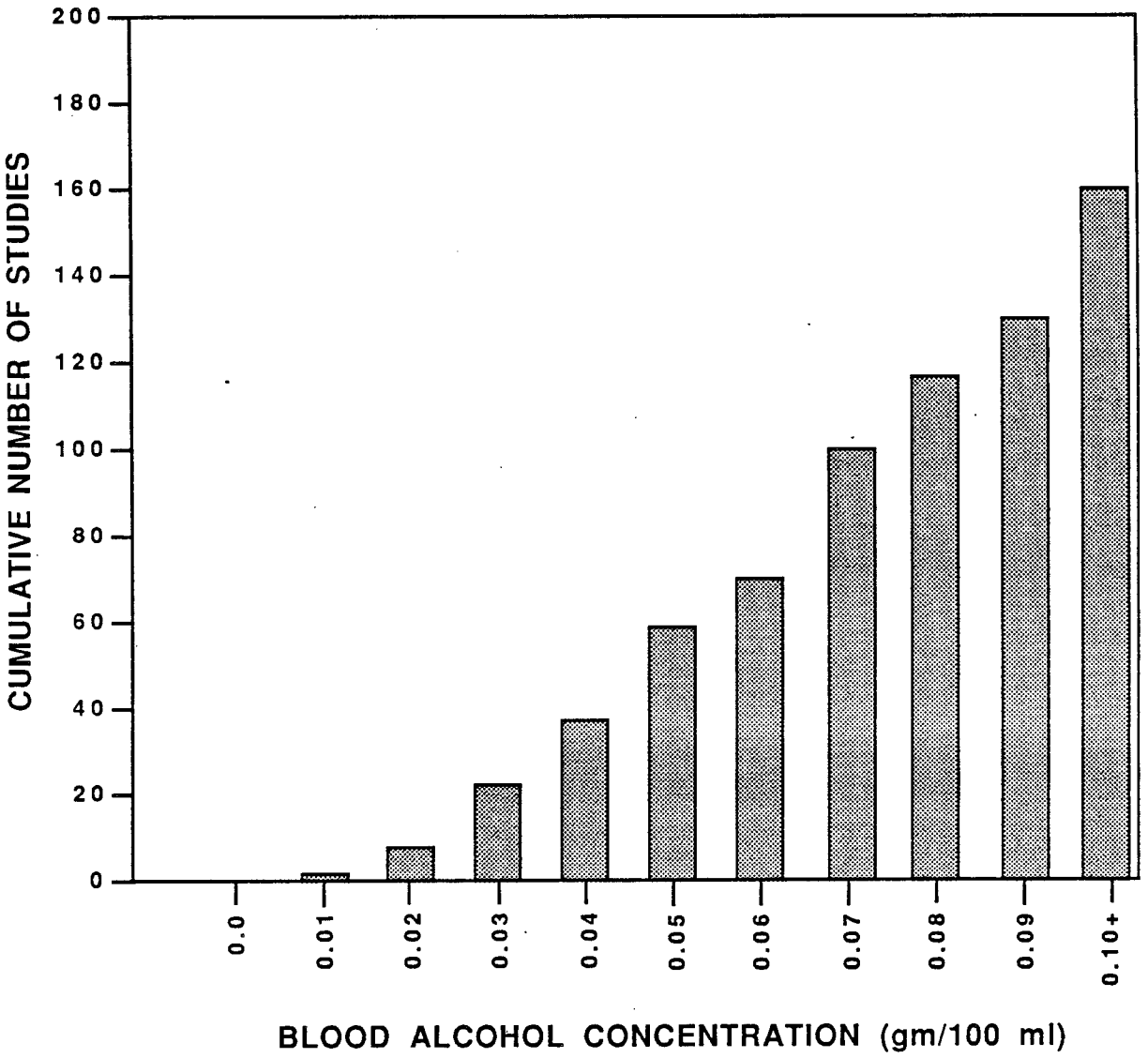
SUMMARY

Figure 14 shows the evidence provided by all of the studies included in this review. This figure presents the cumulative number of studies at or below the BAC at which impairment was first found.

It is apparent that there is no threshold BAC below which impairment effects are absent.

The evidence presented here suggests that information processing skills are particularly affected by low doses of alcohol, as also are skills in divided attention situations. It is also clear that compensatory and pursuit tracking skills are impaired by BACs of 0.05% or more, as are some aspects of optometric visual function. Studies of actual and simulated driving skills have shown performance decrements at BACs as low as 0.03%, thus emphasizing the relevance of findings on alcohol impairment of the aspects of skill reviewed here. On the basis of the present results it can be asserted that BACs of 0.03% or less are sufficient to affect skills relevant to driving, and it is concluded that there is ample scientific evidence to justify the reduction of legal BAC limits to 0.05% or lower.

FIGURE 14
CUMULATIVE NUMBER OF STUDIES SHOWING ALCOHOL EFFECTS ON ALL DRIVING-RELATED SKILLS (A Summary of All Reviewed Studies)



CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The aim of the present review was to consider alcohol effects on aspects of skilled performance related to driving, with a view to assessing the extent of impairment caused by low doses of alcohol. The evidence reviewed here indicates that alcohol does not uniformly impair all aspects of performance. Areas such as oculomotor function and divided attention performance demonstrate that impairment can occur at BACs as low as 0.02%. It is clear, moreover, that BACs of 0.05% or more impair nearly all of the important components of driver performance.

In assessing the minimum BACs required to produce performance decrements relevant to driving, it can be noted that for most of the performance areas discussed here impairment has been reported at BACs between 0.01 and 0.02%. Unfortunately, relatively few studies have investigated the effects of BACs below 0.04%, so that information about the behavioral impairment at BACs below 0.04% is less available than at 0.05% and above. There is sufficient evidence, however, to demonstrate that BACs of 0.05% and more produce impairment of the major components of driver performance: reaction time, tracking, divided attention performance, information processing, oculomotor functions, perception, and other aspects of psychomotor performance. The few studies on alcohol-aggression effects are consistent with frequent reports by police officers of hostile behaviors exhibited by offenders.

The present review has worked from the model provided by Moskowitz (1973a,b), which suggested that driving is a time sharing task, the principal components of which are tracking and visual search and recognition. It is clear that BACs of 0.05% or more impair both of these individual skill components and, at lower levels, also impair the combination of these skills in a divided attention situation. Higher BAC levels (for example, those over 0.10%) also show consistent impairment effects. Evidence from studies of alcohol on actual driving tasks demonstrates that driver performance is similarly affected. Thus, the weight of existing empirical evidence is considered sufficient to scientifically justify the setting of legal BAC limits at 0.05% or lower.

Research on BACs below 0.05% should be encouraged. As noted, there is extensive evidence of performance impairments at these lower BACs, but further studies would permit better definition of the BAC levels at which impairment first appears for different behavioral areas.

Perhaps inevitably, it is recommended that a more systematic and uniform reporting system be adopted for experimental reports in this field. Chapter 2 of this report has provided an extensive discussion of the issues involved in determining BACs, and demonstrates the difficulties faced by reviewers of the area in attempting to provide an assessment of available evidence. It is recommended that researchers be encouraged to provide more detail on their experimental procedures, both as an aid for such assessments, and also to facilitate replication. Further, researchers should be encouraged to adequately consider the implications for their experimental designs of gender

differences, variations in BAC testing procedures, and other factors discussed above. The benefit of adopting these recommendations should be to improve the effectiveness of the collective research effort in this field.

APPENDIX A

DESCRIPTION OF THE BAC DATABASE SYSTEM

The BAC database system was developed to manage and analyze the data for the present review. It was designed to operate on an IBM PC microcomputer, and uses the dBASE III database management software (Ashton-Tate, 1984). The database occupies approximately 2mB of storage, so that the system requirements include a minimum of 256K RAM and a fixed disk drive. The host computer is currently an IBM PC/XT microcomputer operated by the Swinburne Applied Behavioral Studies Centre and configured with 320K RAM, a 10mB fixed disk, and a color graphics system. A set of 32 programs written in the dBASE III programming language performs all necessary operations for adding records to the database, editing and maintaining the database, selecting subsets of the database, and printing reports.

The database consists of a series of datafiles. The master file set (BACLIB) contains citation and methodological information for all entries in the BAC database, and includes text files for abstracts of the cited articles, and an index file to sort records in terms of alphabetic order of author(s) names. In addition there is a datafile for each major task area, including details of the tasks used, all BAC levels studied, and whether or not each BAC was found to show impairment on the task. Programs are available to construct task files from the main database, and to synthesize reports from details stored in both the main database file and one or more task files.

The programs operate through a series of menus so that the system can be employed by a user without extensive computing experience. All but about four of the programs operate in such a way that they are invisible to the user, conducting operations and returning the required information to these main programs. Differing types of procedures show screen displays in different colors to minimize the possibility of confusion or incorrect use of the procedures.

APPENDIX B
REFERENCES

Following is a list of articles used in this report. The 158 articles in the study sample which demonstrated impairment are indicated by an asterick(*). The 19 articles in the study sample which did not demonstrate impairment are indicated by a double asterick (**). Articles with no notation were referenced in the text but were not included in the study sample.

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