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A Review of the Scientific Literature Regarding the Effects of Alcohol on Driving-Related Behavior at Blood Alcohol Concentrations of 0.08 Grams per Deciliter and Lower

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16. Abstract

A review of the scientific literature regarding the effects of alcohol on driving-related skills was conducted. One hundred and twelve articles - from 1981 to 1997 - were reviewed. Results were indexed by BAC and behavioral area and entered into a database. Two separate analyses were conducted. The first analysis determined the lowest BAC at which impairment is reliably present in driving-related skills. The second analysis determined the thresholds of impairment for each of twelve separate behavioral areas. It was concluded that:

1. Alcohol impairs some driving skills beginning with any significant departure from zero BAC. By BACs of 0.05 g/dl, the majority of the experimental studies examined reported significant impairment. By 0.08 g/dl, more than 94% of the studies reviewed exhibited skills impairment.
2. Specific performance skills are differentially affected by alcohol. Some skills are significantly impaired by BACs of 0.01 g/dl, while others do not show impairment until BACs of 0.06 g/dl.
3. Discrepancies between the reported BAC threshold of impairment within a behavioral area reflected a lack of standardization of testing methods, instruments, and measures in the studies reviewed.
4. All drivers are expected to experience impairment in some driving-related skills by 0.08 g/dl or less.

17. Key Words

Alcohol, BAC, Driving Skills, Literature Review

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1. INTRODUCTION

Historically, deterrence has been the principal approach for prevention of driving under the influence of alcohol. Legislatures have established blood alcohol concentration (BAC[1]) limits for driving and law enforcement agencies have enforced those laws. Scientists have contributed to the establishment of BAC limits with data from experimental and epidemiological studies to identify the alcohol levels which produce driving skills impairment and increased crash rates.

In the scientific literature, impairment refers to a statistically significant decrease in performance under alcohol treatment from the performance level exhibited under placebo treatment. To reach statistical significance, performance differences in subjects under the two treatments must be reliable and substantial in magnitude.

In a report published by the National Highway Traffic Safety Administration (NHTSA), Moskowitz and Robinson (1988) reviewed the experimental literature from the 1950's through 1985 on alcohol effects on driving related skills performance. The report summarized 177 studies which met the following criteria for inclusion: Placebo treatments, statistical significance, and the ability to determine the BAC at the time of testing. Overall, 21% of the studies reported performance impairment by 0.04 g/dl, 34% by 0.05 g/dl, 66% by 0.08 g/dl and nearly all by 0.10 g/dl. The skills performance measures were organized into 10 response categories. The BAC at which impairment was first measured and the percent of studies reporting impairment at the various BACs differed by response area. Divided attention, visual functions, and tracking were impaired in the 0.01-0.02 g/dl range, with the number of studies reporting impairment increasing rapidly with increasing BACs. On the other hand, the impairment of simple reaction time and psychomotor measures began at higher BACs. Simple reaction time in particular was found to be an insensitive and unreliable measure.

Moskowitz and Robinson criticized studies which examined performance at one BAC only since a report of impairment at a single BAC sheds no light on the question of whether lower BACs might also be impairing. They concluded that the data identified no threshold BAC below which impairment does not occur. They also concluded that the scientific evidence supported a reduction of the BAC limit for driving to 0.05 g/dl. Finally, to facilitate the classification of examined behaviors, they urged investigators to include fuller descriptions of methods and procedures in reporting future research over a wider range of BACs.

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[1] Alcohol in blood is measured in terms of *weight per volume*. In the US, BACs are typically reported in grams of absolute alcohol per deciliter of whole blood (0.08 g/dl). The symbol "%" is frequently used to denote g/dl. Note, however, that the "%" symbol is not a true percentage since it is describing a measure of weight in a measure of volume.

In this paper, g/dl is the measure utilized. Th values remain the same if the symbol "%" is substituted to g/dl. Other countries frequently use mg/dl (e.g., 80 mg/dl) or g/l (e.g., 0.8 g/l) as their units of measure.

Subsequently Kruger, et al., (1990) in Germany, performed a literature review capturing the European non-English language literature (English summary in Kruger, 1993). The Kruger, et al., review encompassed studies of alcohol effects on subjective reactions such as mood, and social relations, as well as on skills performance. The studies were organized into categories including: subjective reactions, social behaviors, psycho-physical functions, automatic behaviors, controlled behaviors, and driving. The terms automatic and controlled are taken from cognitive psychology theory. Automatic behaviors refer to over-learned tasks which require little conscious mental activity (easy tracking, simple and choice reaction time, mental arithmetic, concentrated attention, etc.). Controlled behaviors involve a greater mental workload (difficult tracking, divided attention tasks, information processing, etc.). Studies of controlled behaviors report impairment beginning at 0.03 g/dl. Impairment appears at somewhat higher BACs for automatic behaviors. The authors concluded that social and controlled behaviors are impaired at 0.030-0.049 g/dl in actual traffic whereas automatic behaviors are not impaired before 0.05 g/dl.

Holloway (1994, 1995) used Kruger's schema in a review for the period 1985 - 1993. In agreement with Kruger, he found that subjective effects and controlled behaviors are affected by alcohol at lower BACs than psycho-physical or automatic behaviors. He reported that 70 to 80% of studies examining controlled behavior and subjective intoxication reported impairment by BACs at or below 0.04 g/dl.

Determining whether a behavior is automatic or controlled, however, can be difficult. Shinar, et al., (1998), for example, demonstrated that the frequent description of gear shifting in a manual transmission vehicle, as an "automatic" process was erroneous. Subjects showed decreased detection of roadside signs during manual shifting in comparison with automatic transmission cars. This is not to argue the potential value of the cognitive psychology model of driving behavior, but as Ranney's (1994) review of driving behavior models noted, accurate assignment of driving activities as controlled or automatic awaits further research. Moskowitz and Robinson (1988) noted the difficulty of assigning studies to behavioral areas given that reports of experimental methods and procedures often are quite limited. As an example, driving simulator studies vary greatly in the types of roads traversed, the degree of interacting traffic, the length of travel, and mental workload. Such variability, which is obvious in simulators, also exists in other measured behaviors. To expand the boundaries of response categories into theoretical groupings without empirical studies validating that placement would only inflate the problem. A fully satisfactory resolution awaits a better taxonomy of behavior which, coupled with better specification and execution of experimental studies, will permit organization of diverse studies into theoretical formats.

This review examines the 1981 to 1998 literature on driving related behavior primarily under low BACs. The behavioral response categories have been organized in a form slightly different from that used by Moskowitz and Robinson (1988). Two caveats apply to the 13 categories of driving-related behaviors in the categorization scheme used in this review. First, note that assignment of tasks to the behavioral categories is arbitrary to some degree and, in some cases, is different from the investigator's categorization. For example, results from an experiment which reported that subjects were required to perform two tracking tasks simultaneously appear under *divided attention* rather than under *tracking*. Second, even within each of the 13 behavioral categories, there is great variability in experimental tasks and corresponding demands on the subjects. An attempt to incorporate the studies into larger categories of a theoretical schema would serve to increase within-category variability and would result in a blurring of distinctions between categories.

2. METHOD

As in the Moskowitz & Robinson (1988) review, the search was limited to experimental measures of skills performance. Without denying the importance of motivational and subjective behaviors as possible factors interacting with alcohol effects on safety, it was our decision that including these response variables would unduly broaden the scope of the review. No one denies, for example, that alcohol increases aggression; there is adequate literature to demonstrate that. What is less clear is how the increased aggressiveness under alcohol would interact with driving behavior. The study of the effects of alcohol on motivation, emotion, etc., therefore, deserves a separate review. This review is confined to more clearly defined measurable variables that are relevant to driving.

Using various search engines, a wide computer search of the literature reporting the effects of alcohol on driving skills was conducted. Abstracts were obtained for 1733 titles produced by the computer search. Based on the content of these abstracts, 358 articles were identified for retrieval and further review. Seventy-three of selected publications were not available.

The 285 published articles retrieved were evaluated to determine whether they met the following, pre-determined inclusion criteria:

- The study's dependent variables were within driving-related behavior,
- BACs at testing time were reported, or the administration of the alcohol treatment was reported in sufficient detail to permit calculation of BACs at the time of behavioral testing,
- Alcohol doses were not above 1 gram of absolute alcohol per kg of subjects' body weight (this was done to insure that peak BACs in the studies reviewed was not above the BAC region of interest for this review),
- Alcohol effects were not confounded with effects of other drugs,
- Human subjects were studied,
- The publication was available in English.

The evaluation determined that 112 studies met the review's inclusion criteria. These 112 articles were reviewed and indexed by driving behavior and BAC, and the pertinent data from each article were entered into a computer data base. Table 1 provides a short description of the behavioral tasks included in the 112 studies by the 13 behavioral domain areas which categorized those studies. It lists the number of articles in each behavioral domain and the number of BAC levels tested across those studies within the domain.

TABLE 1

BEHAVIORAL AREAS AND TASKS, BY ARTICLES AND BAC LEVELS

Domain	Tasks	Number of Articles	Number of BAC Levels
Aftereffects	Testing measured residual alcohol effects on a drinker's performance following a drinking session and the drinker's return to zero BAC. Various tasks from all other domains were used.	12	25
Cognitive Tasks	Digit-symbol substitution, mathematical and verbal reasoning, memory, pattern recognition, visual backward masking, card sorting.	31	145
Critical Flicker Fusion	Determination of the lowest frequency at which a flickering on-off light appears to be constant.	7	18
Divided Attention	Simultaneous performance of two or more tasks such as tracking, visual search, number monitoring, and detection of auditory stimuli.	18	52
Driving Skills	Actual driving, simulated driving, simulated flight, motorcycle simulator.	25	50
Perception	Detection of visual and/or auditory stimuli, time estimation, traffic hazard perception, anticipation time.	12	35
Psychomotor tasks	Finger tapping, body balance, hand steadiness, drill press operation, assembly of electronic parts.	18	57
Reaction time - Choice	Choice reaction time, choice reaction time with auditory distraction.	15	37
Reaction time - Simple	Single known stimulus with a single response.	5	20
Tracking	Pursuit tracking, compensatory tracking, critical tracking.	11	23
Vigilance	Vigilance.	9	18
Visual Functions	Contrast sensitivity, depth perception, smooth pursuit, saccadic peak velocity, saccadic latency, saccadic inaccuracy, nystagmus, etc.	19	63
Drowsiness	Multiple sleep latency test, repeated test of sustained wakefulness.	6	13
Total		112	556

Note: Many articles covered more than one behavioral area

3. RESULTS

The following sections present the results of two approaches in reviewing the literature. The first approach presents the data for impairment across all behavioral areas, counting the *number of studies* with each study counted once at the lowest BAC for which impairment was found. Most studies, however, reported on more than a single measure and, in fact, several reported findings for multiple driving skills across different behavioral areas (i.e., vigilance *and* divided attention *and* psychomotor skills). In addition, several studies reported tests of performance in different behavioral areas and at different BACs. The second analysis, which focused on specific behavioral areas, examined reports of more numerous *behavioral tests* across BACs.

3.1. Overall Impairment

The following analysis is based on 109 of 112 reviewed studies. Three studies were not included. The following is a brief discussion on the rationale for the exclusions.

Willumeit, et al., (1984) described their apparatus as a driving simulator, but it is better described as a tracking device. Subjects moved a light signal in a horizontal plane to coincide with the appearance of a light stimulus. The light signal appeared in one of 50 possible blocks along a horizontal scale. Each appearance of the step signal was preceded by one of two arrows to indicate the direction of stimulus appearance. The study treatments were alcohol, two benzodiazepines, and a beta-blocker. The three drugs and a placebo were administered with and without alcohol for eight treatments total. At 0.05 g/dl BAC, there was no difference between alcohol and placebo treatments. Ten mg diazepam also failed to impair in comparison to placebo. Since this analysis focused on the BAC threshold for impairment, studies in which impairment was not found at any BAC were excluded, whether the result was due to instrument insensitivity, flawed methodology or other cause.

A study by McMillen, et al. (1989), which is described as a study of risk taking in a driving simulator, also was dropped from the analysis. The simulator was a video driving game (Sego, Model 100), and dependent measures were number of lane changes, cars passed, and time at maximum speed during a 4.5 minute drive. A mean BAC of 0.07 g/dl had no effect on any response measure. These results are at variance with studies which report alcohol effects on risk taking (Cohen, et al.,1958; Light and Keiper,1969; Fromme,1997). Similar research has reported that alcohol affects speed selection. Since McMillen, et al. (1989) reported no alcohol effects at the tested BACs, this study was not included in the analysis on the assumption that the measures obtained with the video driving game were insensitive to alcohol.

Finally, one other study was not included, although it did report a response measure sensitive to the effects of alcohol. Yesavage and Leirer (1986) examined the aftereffects of alcohol ingestion. Although other studies of aftereffects include data obtained before subjects' BACs dropped to zero, this one did not. Since it only measured performance at zero BAC, the results do not pertain to the issue of BACs at which alcohol impairment first appears.

Figure 1, based on 109 studies, shows the number of *studies* reporting impairment by the lowest BAC at which impairment appeared. Note that the BAC categories used here are slightly different than those in the Moskowitz and Robinson study. Here each BAC category ends with a 9 (e.g., 0.020-0.029 g/dl) whereas Moskowitz and Robinson used BAC categories ending in zero (e.g., 0.021-0.030 g/dl).

Twenty-seven percent of the studies reported impairment by 0.039 g/dl, 47% by 0.049 g/dl and 92% by 0.079 g/dl. The impairment appeared in one or more of the response variables examined in the study. As shown in Tables B1 and B2 in Appendix B, impairment was reported by more studies and for lower BAC than in the 1988 review by Moskowitz and Robinson. The difference may be accounted for in two ways. First, pre-1988 studies included very few which examined more than one BAC. If impairment is reported only for a single selected BAC, no inference can be drawn about alcohol effects at lower BACs. In this review of more recent literature, the majority of studies have examined multiple BACs, which permits the identification of lower BAC at which impairment appears. Second, the methods and instruments used by researchers in this past decade have improved.

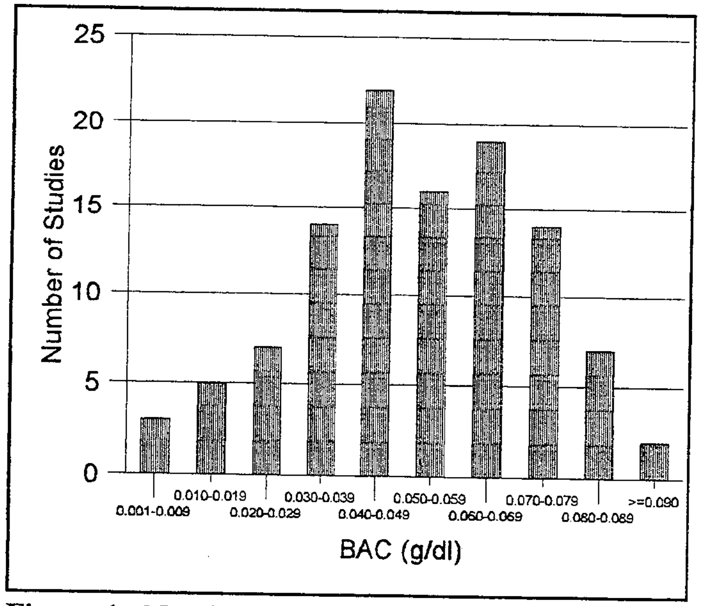

Figure 1. Number of studies reporting impairment (109), by the lowest BAC at which impairment was found.

3.2. Impairment, by Behavioral Areas

The following analysis is based on all 112 reviewed studies. Figure 2 summarizes the number of test *results* by BAC for all the tasks examined. Note that these are not the number of studies, but the total number of tasks across experimental conditions for all studies. In some cases, impairment was reported at BACs as low as 0.009 g/dl. By the time subjects reach BACs of 0.030 g/dl, the number of impaired behavioral areas is greater than the number not impaired. As BACs increase, the number of areas showing impairment also increase. Clearly, the measurement of impairment at very low BACs requires highly sensitive measures. Also, as will be seen later, some behavioral areas are far more sensitive to the effects of alcohol than others. Even within a given area, there was considerable variation in the

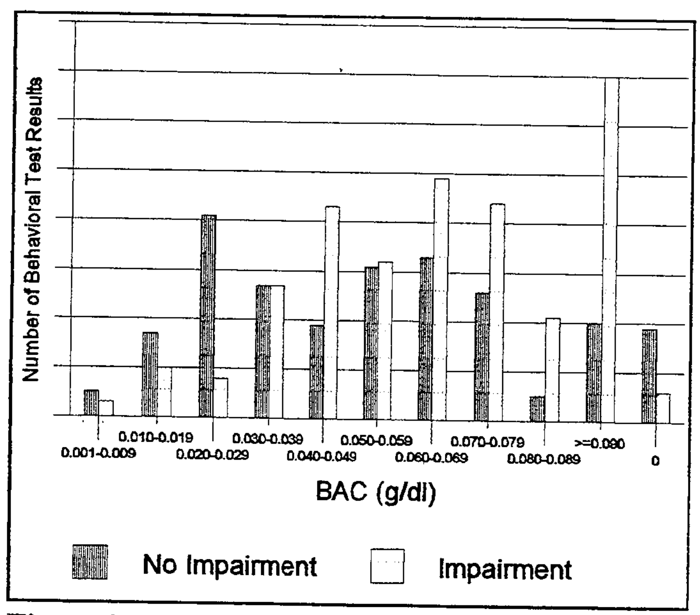

Figure 2. Summary of behavioral tests results (556). Aftereffects are reported at zero BAC.

BAC at which impairment was first reported. As previously noted, it is relevant that experimental procedures vary greatly since procedures affect the sensitivity of response measures. The following are comments on the results within each behavioral areas.

3.2.1. Driving and Flying: On the Road and Simulators (Figure 3, Table 1 in Appendix A).
Twenty-five studies produced a total of 50 behavioral tests. Impairment was reported for BACs below 0.01 g/dl. As shown in Figure 3, nearly all driving and flying simulator studies or on-the-road studies of driving reported impairment by alcohol. The lowest BAC at which impairment was found (0.001 g/dl) was reported by Morrow et al. (1990) who, using a flying simulator, required subjects to integrate information about aircraft, traffic, and weather conditions; maneuver the aircraft along a dynamic flight path; and maintain radio communications.

McMillen et al. (1989) reported the highest BAC at which impairment was not found (0.070 g/dl). The methodological and instrumental problems in that study were discussed in the preceding section.

In the decade since the Moskowitz and Robinson report was published, the sensitivity, reliability and face validity of driving and flying simulators have improved. Driving simulators now present scenarios which better reflect the mental workload of actual driving, which may account for their increased sensitivity to alcohol. Note that subjects in the Morrow et al. study, which reported impairment at 0.001 g/dl, were required to perform multiple tasks simultaneously in a divided attention paradigm.

3.2.2. Divided Attention (Figure 3, Table 2 in Appendix A)
Eighteen studies of divided attention yielded 52 behavioral tests. In general, experimental tasks aimed at measuring the ability to divide attention are sensitive to alcohol effects, beginning at BACs of 0.005-0.010 g/dl. Divided attention tests require subjects to perform two tasks concurrently, and most use a central tracking task and a peripheral visual search task. This approach is appropriate since it models the divided attention characteristics of driving; tracking can be considered analogous to maintaining lane position and visual search corresponds to monitoring the environment. Roehrs et al.(1994) used this configuration and measured impairment at BACs as low as 0.005 g/dl.

A few divided attention tasks use apparatus which requires subjects to simultaneously monitor number displays in central and peripheral vision. This approach appears less sensitive than the combined tracking-visual search task, possibly due to the similarity of the two number tasks and the lack of a continuous component (such as tracking).

3.2.3. Drowsiness (Figure 3, Table 3 in Appendix A)
Although wakefulness is not a measure of skills performance, it is an essential requirement for safe driving. Sleep, or more accurately drowsy driving due to sleep loss or deprivation, has been identified as a contributing variable to crashes, and its potential interaction with alcohol is of import because most alcohol-related crashes occur at night, when drivers are more likely to need sleep.

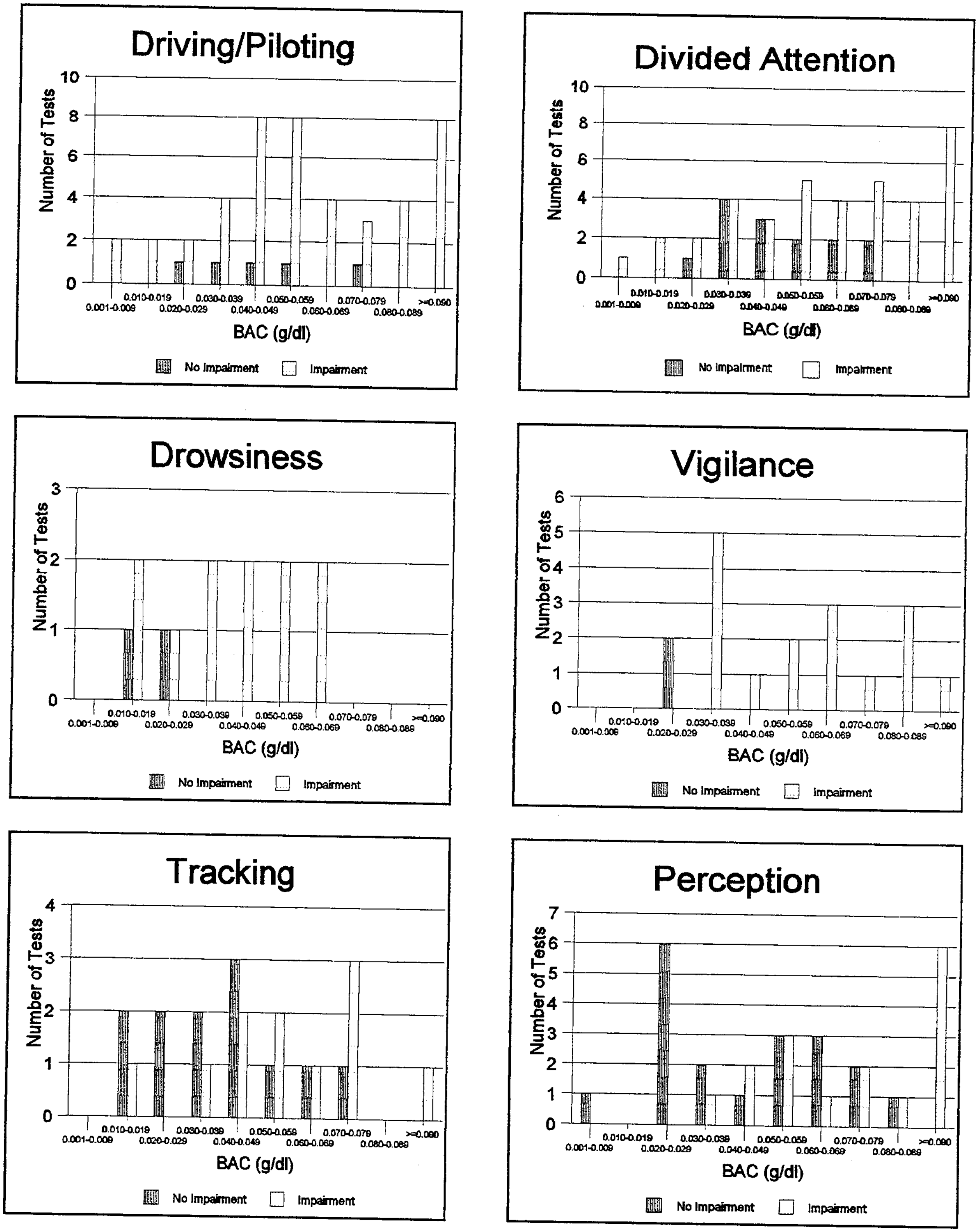

Figure 3. Behavioral test results, by behavioral area.

Six studies of the effects of alcohol on drowsiness produced 13 behavioral test reports of which 11 showed impairment. The findings were obtained with two tests, the multiple sleep latency test (MSLT) and the repeated test of sustained wakefulness (RTSW). The MSLT is a highly standardized measure of physiological sleep tendency. Subjects are connected to polysomnographic equipment, and are given the opportunity to fall asleep at regular intervals. Sleep latency is a measure of elapsed time from when the subjects are told to fall asleep to the occurrence of the first epoch of any sleep stage. The RTSW also measures physiological sleep tendency, but in this test subjects are instructed to resist falling sleep. It has not been validated as extensively as the MSLT.

In general, wakefulness tests were found to be very sensitive to the effects of alcohol. The time to fall asleep was shorter with BACs of 0.010 g/dl and higher, except for two instances, one time at 0.021 g/dl and the other at 0.034 g/dl. The latter result was obtained with the RTSW, arguably the less sensitive of the two test.

3.2.4. Vigilance Tasks (Figure 3, Table 4 in Appendix A)
Nine vigilance studies produced 18 behavioral test results, of which 16 showed alcohol impairment. None of the studies reviewed examined vigilance at BACs below 0.020 g/dl, and two studies reported that there was no impairment at BACs of 0.021 and 0.028 g/dl. Note that one of the studies (Gustafson, 1986) required the subjects to press a switch as rapidly as possible when a tone of 1000 hz at 90 db was presented. A tone of that magnitude might alert subjects and offset the effects of alcohol, particularly at low BACs. At BACs of 0.030 g/dl and above, impairment was reported consistently across all studies.

Vigilance studies which had been published in the literature at the time of the Moskowitz and Robinson review were considerably less likely to show impairment by alcohol. Clearly, since then, more sensitive measures of vigilance have been developed.

3.2.5. Tracking (Figure 3, Table 5 in Appendix A)
Eleven studies of tracking produced 23 behavioral test results. Overall, the results indicated that threshold of impairment varied as a function of the type of tracking task used.

- Adaptive tracking requires subjects to control an index to match the movement of a stimulus which is adjusted in difficulty level to match the ability of the subject. This type of tracking produced mixed findings with impairment found at BACs as low as 0.018 g/dl.

- Pursuit tracking requires subjects to maintain a control index in a constant position relative to a moving index. Fillmore et al. (1994) reported the lowest BAC at which impairment was found (0.054 g/dl).

- Compensatory tracking requires subjects to maintain an index at a predetermined position while a forcing function continuously attempts to move the index off the target (this task is analogous to attempting to maintain lane position in the presence of wind gusts). Four studies reported impairment at 0.060 to 0.100 g/dl. Five reported no impairment at 0.021 to 0.079 g/dl.

- Critical tracking is an unstable compensatory tracking task in which the forcing function gradually increases in magnitude and the test becomes increasingly difficult. Impairment was reported in three tests at BACs between 0.030 and 0.070 g/dl.

3.2.6. Perception (Figure 3, Table 6 in Appendix A)
Twelve studies produced 35 test results. Studies in this category used tasks which differed widely in terms of information processing requirements. Tasks included time estimation, auditory signal detection, visual search, pattern recognition, and traffic hazard perception. The diversity of mental workload is believed to underlie the reported diversity in alcohol sensitivity. In general, the evidence indicates a lack of significant impairment of perceptual abilities below BACs of 0.080 g/dl, although there were some reports of impairment at lower BACs. The lowest impairing BAC (0.037 g/dl) was reported by Lapp et al. (1994), and the highest BAC at which impairment was not found (0.080 g/dl) was reported by Heishman et al., (1997). Interestingly, both of these findings were both obtained with time production/estimation tasks.

Moskowitz and Robinson found perception tasks to be far more sensitive to alcohol than the previous paragraph reports. However, the studies in that earlier review reported on the examination of behaviors quite unlike those examined by investigators in the more recent studies reviewed here.

3.2.7. Visual Functions (Figure 4, Table 7 in Appendix A)
Nineteen studies examined alcohol effects on visual functions, producing a total of 63 behavioral tests. In general, the reports of impairment were consistent at 0.030 g/dl and higher. Many different behavioral functions were included in this category, including visual acuity, contrast sensitivity, eye movements and ocular motor control. Visual acuity appears not to be affected by alcohol below 0.070 g/dl BAC, a finding which is consistent with earlier studies. On the other hand, contrast sensitivity (the ability to discern spatially distinct luminance differences) and tests of oculomotor control were impaired by alcohol at 0.030 g/dl. Mattila et al. (1992), for example, found that subjects' coordination of extra-ocular muscles was significantly affected at 0.026 g/dl.

3.2.8. Cognitive Tasks (Figure 4, Table 8 in Appendix A)
This category encompassed 31 diverse studies with 145 test reports. The tasks varied considerably in assumed information processing characteristics and in sensitivity to alcohol. So perhaps it is not surprising that the appearance of impairment by alcohol varied from as low as 0.005 g/dl to as high as 0.160 g/dl.

Studies of backward masking, a well established measure of information processing rate or perceptual speed, found impairment at 0.030 g/dl (Wilkinson, 1995). Digit-symbol substitution tasks, on the other hand, did not reliably show a deficit until BACs above 0.060 g/dl. Even higher thresholds applied to card sorting, grammatical reasoning, and the Sternberg memory task. Card sorting tests were not generally affected by BACs below 0.090 g/dl, although Lyvers & Maltzman (1991) reported impairment at BACs below 0.050 g/dl. Grammatical and mathematical

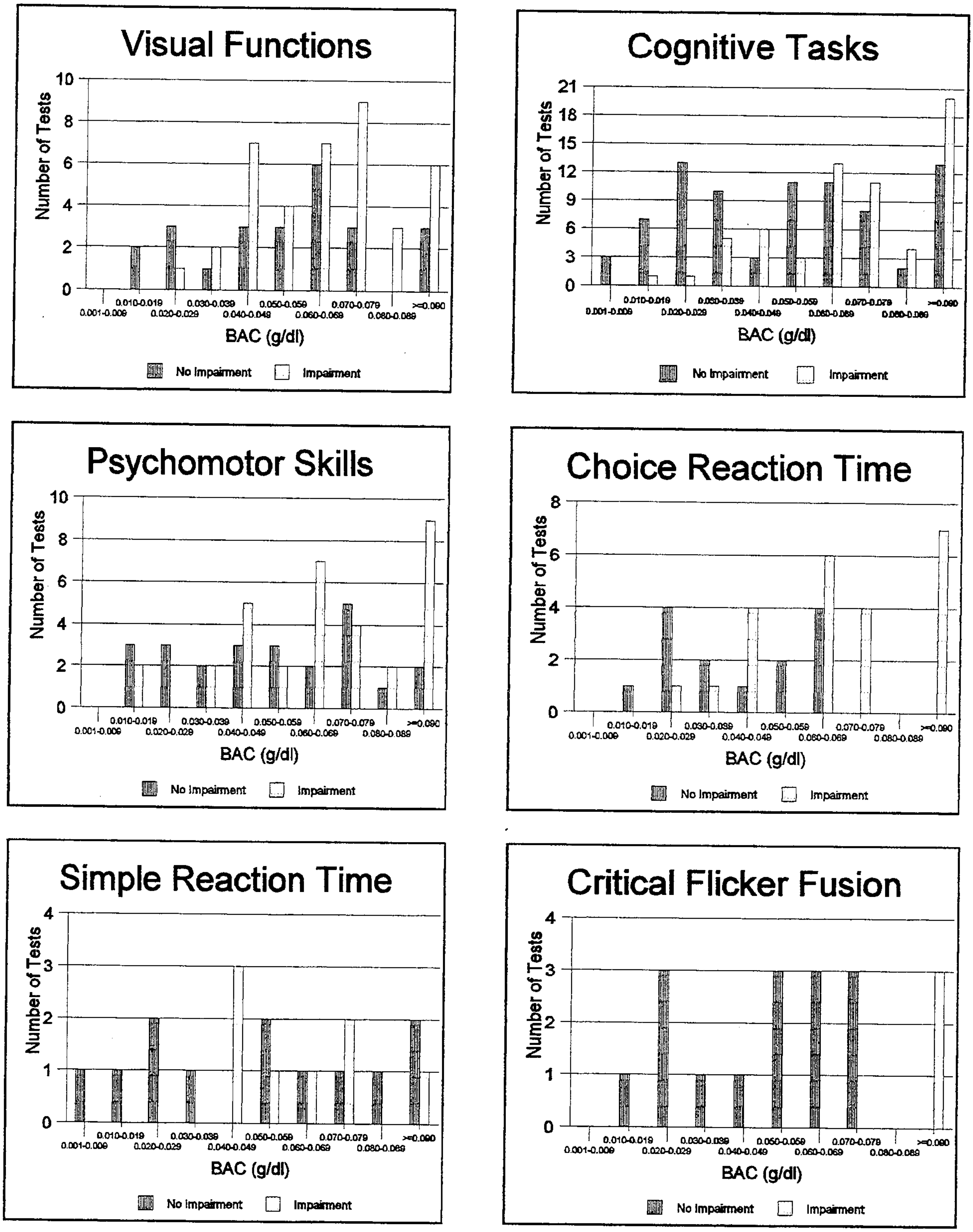

Figure 4. Behavioral test results, by behavioral area.

reasoning tests were not generally affected by BACs below 0.080 g/dl, although Heishman et al. (1997) and Kennedy et al. (1993) reported impairment at BACs of 0.025 g/dl and 0.060 g/dl, respectively. Memory tests, including the Sternberg memory tests, which require subjects to memorize a set of symbols (letters or numbers) and to later determine whether a short sequence of symbols contains the memorized set, were not affected by BACs below 0.060 g/dl. A notable exception was the results reported by Millar et al. (1995) who reported impairment at BACs below 0.020 g/dl in selective reminding tasks.

It is difficult to summarize the evidence concerning alcohol effects on cognitive tasks. As can be recognized, the tasks discussed above have little in common behaviorally, and some are complex and likely require more than one cognitive function.

3.2.9. Psychomotor Skills (Figure 4, Table 9 in Appendix A)
Eighteen studies of the effects of alcohol on psychomotor skills produced 57 tests, 33 of which found impairment and 24 did not. Because of the diverse nature of psychomotor skills and the tests of those skills, it is difficult to establish a threshold for alcohol effects. For that reason, the results have been further divided into three task groups: Finger tapping, body balance, and skilled physical tasks.

- Finger tapping is relatively insensitive to the effects of alcohol. In ten findings for this test only three, at BACs above 0.060 g/dl, reported impairment. The usefulness of finger tapping as a measure of alcohol impairment is questionable.

- The ability to maintain body balance was significantly impaired by alcohol. At BACs above 0.040 g/dl, 65% of the tests showed impairment. At BACs of 0.080 g/dl and above, 100% of the tests showed impairment. This demonstrated sensitivity of body balance is important, since balance tests are used by police officers as a roadside test of sobriety.

- As would be expected, alcohol affected the performance of workplace tasks as a function of the difficulty and complexity of the task. The operation of a drill press, for example, was not affected by BACs below 0.060 g/dl (Price & et al., 1982), but the ability to assemble electronic parts was impaired at 0.049 g/dl (Price et al., 1986). Note that the latter was a relatively difficult task, which required subjects to assemble transistors in specific coordinate locations on a grid board and, upon completion, to insert the unit in a check-out box and adjust a meter read-out to a specified value.

3.2.10. Choice Reaction Time (Figure 4, Table 10 in Appendix A)
Choice reaction time experiments use multiple stimuli and response possibilities, thereby placing a greater information processing load on subjects than simple reaction time. Fifteen choice reaction time studies produced 37 behavioral test results. Although most choice reaction time studies showed impairment by alcohol, it was only at 0.060 g/dl that there were more reports of impairment than of no impairment. By 0.080 g/dl, however, more than 80% of the studies reported evidence of complex reaction time impairment. Differences in findings are attributable to a wide range of

stimulus and response conditions. There is no doubt that choice reaction time is more sensitive to the effects of alcohol than simple reaction time, but a variety of experimental methods under this single rubric leads to differing findings.

3.2.11. Simple Reaction Time (Figure 4, Table 11 in Appendix A)

Five studies with 20 test results at various BACs examined alcohol effects on simple reaction time. Moskowitz & Robinson (1988) concluded that simple reaction time is an insensitive measure. The experiments involve repetitive testing with a single known stimulus and a single known response. Subjects not only know where and what the stimulus is and what the single response option is, they may also be cued when a stimulus is about to occur. As Figure 4 suggests, most experiments using simple reaction time as a measure failed to show any alcohol effects. These tasks, of course, are unrelated to the reaction time demands of actual driving where it is rare for a drivers to know about the initiating stimulus in advance or to know what response will be required.

3.2.12. Critical Flicker Fusion (Figure 4, Table 12 in Appendix A)

In Critical Flicker Fusion (CFF) a subject indicates the threshold at which he/she perceives a flickering on/off light to be constant; that is, not flickering anymore. It has frequently been used in studies of psychoactive drugs. In seven studies at 18 BACs, CFF was an extremely insensitive measure for which impairment occurred only above 0.100 g/dl BAC. Continued use of this test to examine the effects of alcohol on driving related behavior is unwarranted, both because of its insensitivity to alcohol, but also because there is no known relationship to driving.

3.2.13. Aftereffects (Table 13 in Appendix A)

The research area of alcohol aftereffects emerged during the last decade. It examines the residual effects after a positive BAC has declined to zero. Aftereffects are distinguished from hangovers, which are experienced subjectively, and may affect performance without subjective reaction. Twelve studies examined aftereffects of alcohol and produced 25 behavioral test results, of which six reported impairment and 19 did not. A variety of measures included tracking, body sway, eye movements, simple reaction time, critical flicker fusion, symbol copying and others. In the reported impairment, however, only three response measures were used: the MSLT, a flight simulator, and a measure of angular motion.

Reported findings appear to be a direct function of the measures used to study aftereffects. Angular motion, for example, as studied by Ross et al. (1995) used unusually elaborate and complex testing equipment. Subjects were seated in a compartment which rotated clockwise until they reported that the sensation of motion had stopped. Starting from 3 rpm, thresholds for detection of right turns (acceleration of the compartment) and for detection of left turns (deceleration of the compartment) were determined for each individual subject. The subjects' task also included calling out the direction of the turn while depressing a yoke button until the turning ceased, maintaining constant altitude by observing the altimeter and vertical speed indicator, making appropriate yoke inputs, and monitoring for two numbers on a separate visual search task. A significant shift in the threshold of angular motion was observed after the subjects ingested small quantities of alcohol and after a return to zero BAC.

Most other studies used less sensitive measures. Although this area of study has no bearing on the issue of BAC limits, the findings of impairment as a consequence of aftereffects is a traffic safety issue which needs further study.

4. DISCUSSION

4.1 Major Findings

This review of the literature provides strong evidence that impairment of some driving-related skills begins with any departure from zero BAC. By 0.050 g/dl, the majority of studies have reported impairment by alcohol. By BACs of 0.080 g/dl, 94% of the studies reviewed reported impairment. These results include behavioral response areas which are on the one hand insensitive to the effects of alcohol and on the other hand scarcely representative of the demands of driving, such as critical flicker fusion and simple reaction time.

There is evidence that behavioral areas differ in their relative sensitivity to the impairing effects of alcohol. This is in agreement with Moskowitz and Robinson (1988), Kruger (1990), Holloway (1994), and other investigators. Table 2 reports the lowest BACs at which different behavioral areas exhibit impairment.

TABLE 2

BAC AND IMPAIRMENT, BY BEHAVIORAL AREA

BAC (g/dl)	By Lowest BAC at Which Impairment Was Found	By First BAC at Which 50% or More of Behavioral Tests Indicated Consistent Impairment
≥0.100	Critical Flicker Fusion	Simple Reaction Time, Critical Flicker Fusion
0.090-0.099		
0.080-0.089		
0.070-0.079		
0.060-0.069		Cognitive Tasks, Psychomotor Skills, Choice Reaction Time
0.050-0.059		Tracking
0.040-0.049	Simple Reaction Time	Perception, Visual Functions
0.030-0.039	Vigilance, Perception	Vigilance
0.020-0.029	Choice Reaction Time, Visual Functions	
0.010-0.019	Drowsiness, Psychomotor Skills, Cognitive Tasks, Tracking	Drowsiness
0.001-0.009	Driving, Flying, Divided Attention	Driving, Flying, Divided Attention

The first column lists behavioral areas by the lowest BAC at which impairment was found. The second column lists behavioral areas by the first BAC at which 50% of the behavioral tests indicated impairment. That is, the point at which the majority of behavioral tests showed impairment. Note that, with the exceptions of simple reaction time and critical flicker fusion, all driving-related skills exhibited impairment by 0.070 g/dl in more than 50% of tests.

This review supports the suggestion by Ferrara et al. (1993) that discrepancies in test results reflect a lack of standardization in testing methods and that failures to find alcohol impairment at low BACs may be attributable to the use of tasks which are not sensitive to behavioral changes caused by alcohol. If studies only involving driving (in simulators and on the road), simulated piloting, divided attention, and vigilance are examined, 73% of the test results in those areas exhibited impairment by 0.039 g/dl. Including tracking and drowsiness, 65% of the tests performed by 0.039 g/dl showed impairment. Decisions with regard to BAC limit should not be determined on the basis of behavioral areas that are relatively insensitive to alcohol. Crash risk is determined by impairments of those behavioral areas which are important determinants of driving and which are the most sensitive to alcohol.

Virtually all subjects tested in the studies reviewed here exhibited impairment on some critical driving measure by the time they reached 0.080 g/dl.

4.2. Methodological Issues

It is impossible for a reviewer who is not physically present at the execution of the study to stipulate beyond the authors designation how to classify some of these studies. Unfortunately, the variability in results between studies, even within a category, limit the ability to provide advice on the use of response measures to investigate alcohol effects on driving. Researchers in psychometrics, who develop new behavioral tests, are obligated to provide adequate evidence of the validity and reliability of these tests before they are used in measuring behavioral functions in patients. It would appear incumbent on experimental investigators of alcohol and other drug effects to at least provide some defense as to the adequacy of their response measures. Hopefully, this review will contribute to putting to rest the utilization of critical flicker fusion and simple reaction time as measures for examining alcohol effects.

In discussing the imposition of BAC limits, the issue has been raised that not every individual is necessarily impaired at that specific limit. It should be noted that the BAC at which every single individual is impaired has not been an issue in any of the above studies. The requirements of experimental design precludes doing such an analysis. None of the behavioral variables examined, except perhaps for drowsiness, is so over-learned that there are no order or practice effects during an experiment. The majority of studies reported are within-subjects designs where each subject acts as his/her control and where the order of treatment, alcohol or placebo, is counterbalanced. Some subjects receive the alcohol treatment on the second day after their performance has improved from the first placebo treatment day. This makes it difficult to demonstrate impairment in all individuals, since the practice or order effect and the alcohol treatment effect are confounded. It is possible to make the assertion that subjects were impaired by 0.08 g/dl because a substantial majority of subjects would have to exhibit impairment in order for the study to report statistical significance. Thus, even for studies which have reported impairment at 0.010 g/dl, nearly all subjects would have had to demonstrate impairment.

4.3. Future Research

A valuable future area of research would be to examine the interaction of alcohol with sleep deprivation and circadian rhythms. There is strong evidence, produced by the studies on drowsiness, that ability to remain alert and functioning is impaired by alcohol. Nearly all the experiments included in this review involving drowsiness were performed during the day. Noting that the majority of alcohol-related crashes occur at night, it is clear that additional research on time of day is called for.

An additional area which should be examined further is the effects of alcohol on subjective responses. This would include effects on emotion, motivation and judgment. Many theories of driver behavior emphasize motivational and attitudinal factors as important determinants of safety. There is experimental literature demonstrating alcohol effects on aggression and other subjective behaviors. If the importance of the topic is granted, it would appear advisable to review the literature on the role of emotional/motivational factors in driving and the effects of alcohol on such factors. At this point in time, the literature appears incomplete. Note that both Kruger (1990), and Holloway (1994) indicated that subjective reactions were among the most likely to demonstrate impairment at low BACs.

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Appendix A

Tests Results, by Behavioral Area

TABLE A 1

SUMMARY OF TEST RESULTS FOR DRIVING/PILOTING

Author	Year	Experimental Task	BAC	Impairment
Morrow et al.	1990	Flight simulator (severe altitude errors, summary score)	0.001	Yes
Morrow et al.	1993	Flight simulator (severe altitude errors, summary score)	0.002	Yes
Roehrs et al	1994a	Driving simulator (left deviations, right deviations, absolute deviations, points out of range)	0.013	Yes
Morrow et al.	1990	Flight simulator (radio performance, summary score)	0.017	Yes
Louwerens et al.	1987	Driving (standard deviation of lane position, speed variability)	0.024	No
Billings et al.	1991	Flight simulator (serious errors)	0.025	Yes
West et al	1993	Driving (hazard perception)	0.025	Yes
Ross et al.	1992	Flight simulator (instrument departure procedural errors)	0.030	Yes
Willumeit et al.	1984	Driving simulator (composite score)	0.032	No
Ross et al.	1992	Flight simulator (intersection holding errors, basic IFR flight control errors, degree of error in position reports, failure to question clearance, communication errors)	0.033	Yes
Ross et al.	1992	Flight simulator (instrument departure procedural errors)	0.034	Yes
Ross et al.	1992	Flight simulator (intersection holding errors, basic IFR flight control errors, degree of error in position reports, failure to question clearance, communication errors)	0.035	Yes
Gengo et al.	1990	Driving simulator (standard deviation of reaction time)	0.040	Yes
Mongrain	1989	Driving simulator	0.040	Yes
Ross & Mundt	1988	Flight simulator (composite score)	0.040	Yes
Brookhuis & De Waard	1993	Driving (car following, standard deviation of lane position)	0.041	Yes
Morrow et al.	1990	Flight simulator	0.041	Yes
Morrow et al.	1993	Flight simulator (severe altitude errors, summary score)	0.042	Yes
Vermeeren & O'Hanlon	1998	Driving (standard deviation of lane position)	0.045	Yes
Roehrs et al	1994a	Driving simulator (left deviations, right deviations, absolute deviations, points out of range)	0.049	Yes
Willumeit et al.	1984	Driving simulator (composite score)	0.049	No
Smiley et al.	1987	Driving (speed on open road curves, peripheral stimuli detected, and standard deviation of velocity on runway curves)	0.050	Yes
West et al	1993	Driving (hazard perception)	0.050	Yes
Willumeit et al.	1984	Driving simulator (composite score)	0.050	No

TABLE A 1

SUMMARY OF TEST RESULTS FOR DRIVING/PILOTING

Author	Year	Experimental Task	BAC	Impairment
Gawron & Ranney	1988	Driving (curve lateral position deviation, straight lateral position deviation, right road departure, curve speed deviation, straight speed deviation, time between same-side departures)	0.053	Yes
Gawron & Ranney	1988	Driving simulator (lateral position, number of times over the speed limit)	0.053	Yes
Allen	1996	Driving simulator (mean response time, throttle activity, curve error, standard deviation of lane position)	0.055	Yes
Morrow et al.	1990	Flight simulator (course performance, radio performance, summary score)	0.056	Yes
Horne & Baumber	1991	Driving simulator (mean following distance, standard deviation of mean following distance)	0.058	Yes
Colburn et al.	1993	Motorcycle simulator (leaving the roadway, total errors)	0.059	Yes
Flanagan et al.	1983	Driving (penalty points)	0.060	Yes
Louwerens et al.	1987	Driving (standard deviation of lane position, speed variability)	0.060	Yes
Horne & Baumber	1991	Driving simulator (mean following distance, standard deviation of mean following distance)	0.064	Yes
Rimm et al.	1982	Driving simulator (braking, steering)	0.064	Yes
McMillen et al.	1989	Driving simulator (lane changes, cars passed, time at maximum speed)	0.070	No
Ranney & Gawron	1986	Driving simulator (number of times over the speed limit)	0.070	Yes
Morrow et al.	1993	Flight simulator (severe altitude errors, summary score)	0.071	Yes
Taylor et al.	1994	Flight simulator (traffic avoidance, cockpit monitoring, landing)	0.077	Yes
Smiley et al.	1987	Driving (speed on open road curves, peripheral stimuli detected, and standard deviation of velocity on runway curves)	0.080	Yes
Taylor et al.	1996	Flying simulator (summary scores)	0.080	Yes
Louwerens et al.	1987	Driving (standard deviation of lane position, speed variability)	0.085	Yes
Colburn et al.	1993	Motorcycle simulator (leaving the roadway, total errors)	0.088	Yes
Morrow et al.	1990	Flight simulator (course performance, radio performance, severe altitude errors, summary score)	0.098	Yes
Morrow et al.	1993	Flight simulator (severe altitude errors, summary score)	0.101	Yes
Yesavage et al.	1994	Flight simulator (composite score)	0.101	Yes

TABLE A 1

SUMMARY OF TEST RESULTS FOR DRIVING/PILOTING

Author	Year	Experimental Task	BAC	Impairment
Gawron & Ranney	1988	Driving (curve lateral position, curve lateral position deviation, straight lateral position deviation, left road departure, right road departure, curve speed, curve speed deviation, straight speed deviation, time between same-side departures, time outside lane)	0.103	Yes
Gawron & Ranney	1988	Driving simulator (# of obstacles struck, lateral position, number of times over the speed limit, total heading error, total lateral position errors)	0.103	Yes
Mongrain	1989	Driving simulator	0.120	Yes
Ranney & Gawron	1986	Driving simulator (curve heading error, curve lateral position, fixed curve lateral position, number of obstacles struck, number of times over the speed limit)	0.120	Yes
Louwerens et al.	1987	Driving (standard deviation of lane position, speed variability)	0.122	Yes

TABLE A 2

SUMMARY OF TEST RESULTS FOR DIVIDED ATTENTION

Author	Year	Experimental Task	BAC	Impairment
Roehrs et al	1994b	Divided attention task	0.008	Yes
Roehrs et al	1994a	Tracking and visual search	0.013	Yes
Millar et al.	1992	Primary tracking and secondary visual reaction time	0.014	Yes
Hindmarch et al	1992	Tracking and visual search	0.020	No
Landauer & Howat	1983	Tracking and peripheral visual search	0.021	Yes
Mattila et al.	1992	Tracking and secondary task	0.026	Yes
Millar et al.	1992	Primary tracking and secondary visual reaction time	0.030	Yes
Mills & Bisgrove	1983a	Central and peripheral number monitoring	0.030	No
Mills & Bisgrove	1983b	Central and peripheral number monitoring	0.030	Yes
Wilkinson	1995	Compensatory tracking and visual search task	0.030	Yes
Wilkinson et al.	1989	Compensatory tracking and visual search task	0.030	Yes
Himdmarch et al.	1991	Compensatory tracking and detection of visual stimuli	0.033	No
Roehrs et al.	1993	Divided attention task	0.035	No
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.036	No
Finnigan et al.	1995	Primary tracking and visual secondary RT task	0.040	No
Krueger	1986	Compensatory tracking, number monitoring and visual perception	0.040	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.041	No
Marks and MacAvoy	1989	Central and peripheral light monitoring	0.043	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.047	No
Roehrs et al	1994a	Tracking and visual search	0.049	Yes
Landauer & Howat	1983	Tracking and peripheral visual search	0.050	Yes
Lex et al.	1994	Compensatory tracking and visual search task	0.050	No
Mattila et al.	1992	Tracking and secondary task	0.050	Yes
Wilkinson	1995	Compensatory tracking and visual search task	0.050	Yes
Hindmarch et al	1992	Tracking and visual search	0.052	No
Roehrs et al.	1989	Divided attention task	0.055	Yes
Finnigan et al.	1995	Primary tracking and visual secondary RT task	0.056	Yes
Lex et al.	1994	Compensatory tracking and visual search task	0.060	No

TABLE A 2

SUMMARY OF TEST RESULTS FOR DIVIDED ATTENTION

Author	Year	Experimental Task	BAC	Impairment
Millar et al.	1992	Primary tracking and secondary visual reaction time	0.060	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.062	Yes
Finnigan et al.	1995	Primary tracking and visual secondary RT task	0.063	Yes
Himdmarch et al.	1991	Compensatory tracking and detection of visual stimuli	0.066	No
Maylor et al.	1990	Tracking and auditory detection	0.068	Yes
Lex et al.	1994	Compensatory tracking and visual search task	0.070	No
Wilkinson & Moskowitz	1989	Compensatory tracking and visual search task	0.070	Yes
Landauer & Howat	1983	Tracking and peripheral visual search	0.073	Yes
Finnigan et al.	1995	Primary tracking and visual secondary RT task	0.075	Yes
Lex et al.	1994	Compensatory tracking and visual search task	0.075	No
Mattila et al.	1992	Tracking and secondary task	0.076	Yes
Hindmarch et al	1992	Tracking and visual search	0.078	Yes
Krueger	1986	Compensatory tracking, number monitoring and visual perception	0.080	Yes
Lex et al.	1994	Compensatory tracking and visual search task	0.080	Yes
Wilkinson	1995	Compensatory tracking and visual search task	0.080	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.089	Yes
Marks and MacAvoy	1989	Central and peripheral light monitoring	0.093	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.095	Yes
Hindmarch et al	1992	Tracking and visual search	0.100	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.100	Yes
Himdmarch et al.	1991	Compensatory tracking and detection of visual stimuli	0.104	Yes
Mills & Bisgrove	1983	Central and peripheral number monitoring	0.106	Yes
Krueger	1986	Compensatory tracking, number monitoring and visual perception	0.120	Yes
Himdmarch et al.	1991	Compensatory tracking and detection of visual stimuli	0.142	Yes

TABLE A 3

SUMMARY OF TEST RESULTS FOR DROWSINESS

Author	Year	Experimental Task	BAC	Impairment
Roehrs et al	1994b	Multiple sleep latency test	0.010	Yes
Roehrs et al	1994a	Multiple sleep latency test	0.013	Yes
Roehrs et al.	1989	Multiple sleep latency test	0.020	Yes
Papineau et al.	1998	Multiple sleep latency test	0.021	No
Walsh et al.	1991	Multiple sleep latency test	0.034	Yes
Walsh et al.	1991	Repeated test of sustained Wakefulness	0.034	No
Roehrs et al.	1993	Multiple sleep latency test	0.035	Yes
Roehrs et al	1994b	Multiple sleep latency test	0.040	Yes
Roehrs et al	1994a	Multiple sleep latency test	0.049	Yes
Roehrs et al.	1989	Multiple sleep latency test	0.050	Yes
Papineau et al.	1998	Multiple sleep latency test	0.055	Yes
Roehrs et al	1994b	Multiple sleep latency test	0.060	Yes
Roehrs et al.	1989	Multiple sleep latency test	0.060	Yes

TABLE A 4

SUMMARY OF TEST RESULTS FOR VIGILANCE

Author	Year	Experimental Task	Domain	BAC	Impairment
Gustafson	1986	Auditory RT in a Sustained attention setting	Vigilance	0.021	No
Gustafson	1986	Visual RT in a Sustained attention setting	Vigilance	0.028	No
Rohrbaugh et al.	1987	Sustained attention	Vigilance	0.030	Yes
Rohrbaugh et al.	1988	Sustained attention	Vigilance	0.030	Yes
Wilkinson	1995	Sustained attention	Vigilance	0.030	Yes
Wilkinson & Moskowitz	1989	Sustained attention	Vigilance	0.030	Yes
Horne & Gibbons	1991	Auditory Sustained attention	Vigilance	0.034	Yes
Vermeeren & O'Hanlon	1998	Sustained attention	Vigilance	0.045	Yes
Jansen et al.	1985	Sustained attention	Vigilance	0.054	Yes
Gustafson	1986	Visual RT in a Sustained attention setting	Vigilance	0.059	Yes
Rohrbaugh et al.	1988	Sustained attention	Vigilance	0.063	Yes
Rohrbaugh et al.	1987	Sustained attention	Vigilance	0.065	Yes
Horne & Gibbons	1991	Auditory Sustained attention	Vigilance	0.066	Yes
Wilkinson & Moskowitz	1989	Sustained attention	Vigilance	0.070	Yes
Wilkinson	1995	Sustained attention	Vigilance	0.080	Yes
Rohrbaugh et al.	1988	Sustained attention	Vigilance	0.086	Yes
Gustafson	1986	Auditory RT in a Sustained attention setting	Vigilance	0.088	Yes
Rohrbaugh et al.	1987	Sustained attention	Vigilance	0.090	Yes

TABLE A 5

SUMMARY OF TEST RESULTS FOR TRACKING

Author	Year	Experimental Task	BAC	Impairment
Mangold at al.	1996	Pursuit tracking	0.011	No
Mangold at al.	1996	Pursuit tracking	0.014	No
Cohen at al.	1987	Adaptive tracking	0.018	Yes
Hindmarch et al	1992	Tracking	0.020	No
Kuitunen et al.	1990	Tracking error severity index	0.021	No
Wilkinson & Moskowitz	1989	Critical tracking	0.030	Yes
Mangold at al.	1996	Pursuit tracking	0.036	No
van Steveninck et al.	1993	Adaptive tracking	0.038	No
Kuitunen et al.	1990	Tracking error severity index	0.040	No
Cohen at al.	1987	Adaptive tracking	0.043	No
Mangold at al.	1996	Pursuit tracking	0.043	No
Cohen at al.	1987	Adaptive tracking	0.044	Yes
Vermeeren & O'Hanlon	1998	Critical tracking	0.045	Yes
Hindmarch et al	1992	Tracking	0.052	No
Fillmore & Vogel-Sprott	1994	Pursuit Rotor Task	0.054	Yes
Fillmore & Vogel-Sprott	1995	Pursuit Rotor Task	0.058	Yes
Kuitunen et al.	1990	Tracking error severity index	0.060	Yes
Maylor et al.	1990	Pursuit tracking	0.068	No
Wilkinson & Moskowitz	1989	Critical tracking	0.070	Yes
Collins et al	1987	Compensatory tracking	0.077	Yes
Hindmarch et al	1992	Tracking	0.078	No
Kuitunen et al.	1990	Tracking error severity index	0.079	Yes
Hindmarch et al	1992	Tracking	0.100	Yes

TABLE A 6

SUMMARY OF TEST RESULTS FOR PERCEPTION

Author	Year	Experimental Task	BAC	Impairment
Heishman et al.	1997	Time estimation	0.005	No
MacArthur et al/	1982	Direction judgement	0.020	No
Heishman et al.	1997	Time estimation	0.025	No
Wang et al.	1992	Anticipation time	0.025	No
Gustafson	1986	Visual search task	0.027	No
Maylor et all.	1987	Visual search task	0.028	No
Post et al.	1996	Visual spatial attention	0.028	No
Wang et al.	1992	Anticipation time	0.030	No
Willumeit et al	1984	Audio-visual perception	0.032	No
Lapp et al.	1994	Time estimation	0.037	Yes
Mongrain	1989	Signal detection	0.040	Yes
Wang et al.	1992	Anticipation time	0.047	Yes
Willumeit et al	1984	Audio-visual perception	0.049	No
Deery & Love	1996	Traffic hazard perception	0.050	Yes
Wang et al.	1992	Anticipation time	0.050	No
Willumeit et al	1984	Audio-visual perception	0.050	No
Baker	1985	Pattern reproduction following short visual presentation	0.055	Yes
Wang et al.	1992	Anticipation time	0.055	No
Gustafson	1986	Visual search task	0.058	Yes
MacArthur et al.	1982	Direction judgement	0.060	No
Wang et al.	1992	Anticipation time	0.060	No
Wang et al.	1992	Anticipation time	0.065	No
Maylor et al.	1990	Auditory detection task	0.068	Yes
Wang et al.	1992	Anticipation time	0.070	No
Wang et al.	1992	Anticipation time	0.075	No
Lapp et al.	1994	Time estimation	0.078	Yes
Post et al.	1996	Visual spatial attention	0.078	Yes
Heishman et al.	1997	Time estimation	0.080	No
Mongrain	1989	Signal detection	0.080	Yes

TABLE A 6

SUMMARY OF TEST RESULTS FOR PERCEPTION

Author	Year	Experimental Task	BAC	Impairment
Wang et al.	1992	Anticipation time	0.090	Yes
Wang et al.	1992	Anticipation time	0.095	Yes
Wang et al.	1992	Anticipation time	0.100	Yes
Mongrain	1989	Signal detection	0.120	Yes
Maylor et all.	1987	Visual search task	0.130	Yes
Mongrain	1989	Signal detection	0.160	Yes

TABLE A 7

SUMMARY OF TEST RESULTS FOR VISUAL FUNCTIONS

Author	Year	Experimental Task	BAC	Impairment
Nicholson et al.	1994	Contrast sensitivity	0.011	No
Cohen et al.	1987	Eye movements	0.018	No
Kuitunen et al.	1990	Coordination of extraocular muscles	0.021	No
Wang et al.	1992	Visual sensitivity, depth perception	0.025	No
Mattila et al.	1992	Coordination of extraocular muscles	0.026	Yes
Mattila et al.	1992	Nystagmus	0.026	No
Wang et al.	1992	Visual sensitivity, depth perception	0.030	No
Ross & Mughni	1995	Flight simulator (detection of angular acceleration)	0.037	Yes
van Steveninck et al.	1993	Smooth pursuit, saccadic peak velocity, saccadic latency, saccadic inaccuracy	0.038	Yes
Katoh	1988	Eye saccadic velocity	0.040	Yes
Kuitunen et al.	1990	Coordination of extraocular muscles	0.040	No
Cohen et al.	1987	Eye movements	0.043	Yes
Nicholson et al.	1994	Contrast sensitivity	0.043	Yes
Hogan & Gilmartin	1985	Amplitude of accomodation, tonic accomodation	0.045	No
Hogan & Gilmartin	1985	Heterophoria (6m), heterophoria (33cm), Accomodative-convergence/accomodation ratio, lateral fusional ability, near point of convergence	0.045	Yes
Wang et al.	1992	Depth perception	0.047	Yes
Wang et al.	1992	Visual sensitivity	0.047	No
Katoh	1988	Eye saccadic velocity	0.048	Yes
Barnes et al.	1985	Eye velocity	0.049	Yes
Mattila et al.	1992	Coordination of extraocular muscles	0.050	Yes
Mattila et al.	1992	Nystagmus	0.050	Yes
Pearson & Timney	1998	Contrast sensitivity	0.050	Yes
Wang et al.	1992	Depth perception	0.050	Yes
Wang et al.	1992	Visual sensitivity	0.050	No
Wang et al.	1992	Visual sensitivity, depth perception	0.050	No
Wang et al.	1992	Visual sensitivity, depth perception	0.055	No
Kuitunen et al.	1990	Coordination of extraocular muscles	0.060	No

TABLE A 7

SUMMARY OF TEST RESULTS FOR VISUAL FUNCTIONS

Author	Year	Experimental Task	BAC	Impairment
Pearson & Timney	1998	Contrast sensitivity	0.060	Yes
Wang et al.	1992	Depth perception	0.060	Yes
Wang et al.	1992	Visual sensitivity	0.060	No
Hill & Toffolon	1990	Visual acuity, color vision, stereo vision	0.061	No
Hill & Toffolon	1990	Horizontal visual field, vertical visual field, accomodation, convergence	0.061	Yes
Wang et al.	1992	Depth perception	0.065	Yes
Wang et al.	1992	Visual sensitivity	0.065	No
Katoh	1988	Eye saccadic velocity	0.066	Yes
Reker	1988	Latency of isolated eye	0.066	No
Reker	1988	Velocity of isolated eye, coordinated head-eye movement	0.066	Yes
Hogan & Linfield	1983	Accomodative-convergence/accomodation ratio, near heterophoria, positive fusional ability, accomodation	0.067	No
Hogan & Linfield	1983	Negative fusional ability, distance heterophoria, near point of convergence	0.067	Yes
Pearson & Timney	1998	Contrast sensitivity	0.070	Yes
Wang et al.	1992	Depth perception	0.070	Yes
Wang et al.	1992	Visual sensitivity	0.070	No
Andre	1996	Contrast sensitivity	0.073	Yes
Barnes et al.	1985	Eye displacement gain, eye velocity, vestibulo-ocular response	0.073	Yes
Wang et al.	1992	Depth perception	0.075	Yes
Wang et al.	1992	Visual sensitivity	0.075	No
Leibowitz, et al.	1992	Contrast sensitivity	0.076	Yes
Mattila et al.	1992	Coordination of extraocular muscles	0.076	Yes
Mattila et al.	1992	Nystagmus	0.076	Yes
Barnes	1984	Visual pursuit, vestibular-ocular reflex suppression	0.077	Yes
Kuitunen et al.	1990	Coordination of extraocular muscles	0.079	No
Zulauf et al.	1988	Contrast sensitivity	0.080	Yes
Katoh	1988	Eye saccadic velocity	0.085	Yes
Andre	1994	Contrast sensitivity	0.088	Yes

TABLE A 7

SUMMARY OF TEST RESULTS FOR VISUAL FUNCTIONS

Author	Year	Experimental Task	BAC	Impairment
Wang et al.	1992	Depth perception	0.090	Yes
Wang et al.	1992	Visual sensitivity	0.090	No
Wang et al.	1992	Depth perception	0.095	Yes
Wang et al.	1992	Visual sensitivity	0.095	No
Pearson & Timney	1998	Contrast sensitivity	0.100	Yes
Wang et al.	1992	Depth perception	0.100	Yes
Wang et al.	1992	Visual sensitivity	0.100	No
Reker	1988	Latency of isolated eye, velocity of isolated eye, coordinated head-eye movement	0.107	Yes
Hill & Toffolon	1990	Visual acuity, horizontal visual field, vertical visual field, color vision, stereo vision, accomodation, convergence	0.134	Yes

TABLE A 8

SUMMARY OF TEST RESULTS FOR COGNITIVE TASKS

Author	Year	Experimental Task	BAC	Impairment
Heisman	1997	Digit-symbol substitution	0.005	No
Heisman	1997	Number recognition	0.005	No
Heisman	1997	Word recall	0.005	No
Mangold et al.	1996	Digit-symbol substitution	0.011	No
Mangold et al.	1996	Digit-symbol substitution	0.014	No
Millar et al.	1992	Auditory short-term memory	0.014	No
Pickworth et al.	1997	Card sorting	0.014	No
Pickworth et al.	1997	Digit-symbol substitution	0.014	No
Pickworth et al.	1997	Letter search	0.014	No
Pickworth et al.	1997	Serial addition/subtraction	0.014	No
Millar et al.	1995	Recognition and memory task	0.016	Yes
Hindmarch et al	1992	Color test	0.020	No
Hindmarch et al	1992	Digit-symbol substitution	0.020	No
Hindmarch et al	1992	Letter recognition	0.020	No
Hindmarch et al	1992	Mental arithmetic	0.020	No
Hindmarch et al	1992	Spatial orientation	0.020	No
Hindmarch et al	1992	Sternberg	0.020	No
Hindmarch et al	1992	Sternberg	0.020	No
Kuitunen et al.	1990	Digit-symbol substitution	0.021	No
Kuitunen et al.	1990	Symbol copying	0.021	No
Heisman	1997	Digit-symbol substitution	0.025	No
Heisman	1997	Number recognition	0.025	Yes
Heisman	1997	Word recall	0.025	No
Mattila et al.	1992	Digit-symbol substitution	0.026	No
Hindmarch et al.	1991	Sternberg	0.027	No
Millar et al.	1992	Auditory short-term memory	0.030	No
Wilkinson	1995	Sternberg	0.030	No
Wilkinson	1995	Visual backward masking	0.030	Yes
Roehrs et al.	1993	Digit-symbol substitution	0.035	Yes

TABLE A 8

SUMMARY OF TEST RESULTS FOR COGNITIVE TASKS

Author	Year	Experimental Task	BAC	Impairment
Mangold et al.	1996	Digit-symbol substitution	0.036	No
Pickworth et al.	1997	Card sorting	0.036	No
Pickworth et al.	1997	Digit-symbol substitution	0.036	No
Pickworth et al.	1997	Letter search	0.036	No
Pickworth et al.	1997	Serial addition/subtraction	0.036	No
Lamb & Robertson	1987	Pattern recognition	0.037	No
Doms et al.	1988	Cross-out groups of four dots	0.038	Yes
Doms et al.	1988	Cross-out letter configuration	0.038	No
Doms et al.	1988	Memory	0.038	Yes
Doms et al.	1988	Symbol marking	0.038	Yes
van Steveninck	1993	Digit-symbol substitution	0.038	No
Kuitunen et al.	1990	Digit-symbol substitution	0.040	No
Kuitunen et al.	1990	Symbol copying	0.040	No
Hasenfratz et al.	1993	Digit patterns recognition	0.042	Yes
Mangold et al.	1996	Digit-symbol substitution	0.043	No
Millar et al.	1995	Recognition and memory task	0.043	Yes
de Wit et al.	1987	Digit-symbol substitution	0.046	Yes
Ryan et al.	1996	Item recognition	0.048	Yes
Hartley & Coxon	1984	Reading comprehension	0.049	Yes
Lyvers & Maltzman	1991	Card sorting	0.049	Yes
Lukas et al.	1989	Digit-symbol substitution	0.050	No
Mattila et al.	1992	Digit-symbol substitution	0.050	Yes
Wilkinson	1995	Sternberg	0.050	No
Wilkinson	1995	Visual backward masking	0.050	Yes
Hindmarch et al	1992	Color test	0.052	No
Hindmarch et al	1992	Digit-symbol substitution	0.052	No
Hindmarch et al	1992	Letter recognition	0.052	No
Hindmarch et al	1992	Mental arithmetic	0.052	No
Hindmarch et al	1992	Spatial orientation	0.052	No

TABLE A 8

SUMMARY OF TEST RESULTS FOR COGNITIVE TASKS

Author	Year	Experimental Task	BAC	Impairment
Hindmarch et al	1992	Sternberg	0.052	No
Hindmarch et al	1992	Sternberg	0.052	No
Baker	1985	Digit recall	0.055	No
Baker	1985	Velocity estimation	0.055	Yes
Lukas et al.	1989	Digit-symbol substitution	0.058	No
Gengo et al.	1990	Digit-symbol substitution	0.060	Yes
Kennedy et al	1993	Code substitution	0.060	Yes
Kennedy et al	1993	Grammatical reasoning	0.060	No
Kennedy et al	1993	Mathematical processing	0.060	Yes
Kennedy et al	1993	Pattern discrimination	0.060	Yes
Kennedy et al	1993	Spatial orientation	0.060	Yes
Kennedy et al	1993	Sternberg	0.060	Yes
Kuitunen et al.	1990	Digit-symbol substitution	0.060	Yes
Kuitunen et al.	1990	Symbol copying	0.060	No
Lex et al.	1988	Card rotation	0.060	No
Lex et al.	1988	Sentence completion	0.060	No
Lex et al.	1988	Identification of repetitions of sample digits	0.060	Yes
Millar et al.	1992	Auditory short-term memory	0.060	No
Lamb & Robertson	1987	Pattern recognition	0.061	Yes
Lukas et al.	1989	Digit-symbol substitution	0.062	No
Pickworth et al.	1997	Card sorting	0.062	No
Pickworth et al.	1997	Digit-symbol substitution	0.062	No
Pickworth et al.	1997	Letter search	0.062	No
Pickworth et al.	1997	Serial addition/subtraction	0.062	No
Maylor et al.	1990	Recall	0.064	Yes
Maylor et al.	1990	Reading	0.064	Yes
Fillmore et al.	1998	Digit patterns recognition	0.066	Yes
Hindmarch et al.	1991	Sternberg	0.066	No
Maylor et al.	1989	Letter recognition	0.069	Yes

TABLE A 8

SUMMARY OF TEST RESULTS FOR COGNITIVE TASKS

Author	Year	Experimental Task	BAC	Impairment
Lukas et al.	1989	Digit-symbol substitution	0.070	Yes
Lukas et al.	1989	Digit-symbol substitution	0.075	Yes
Mattila et al.	1992	Digit-symbol substitution	0.076	Yes
Ryan et al.	1996	Item recognition	0.076	Yes
Collins et al	1987	Mental arithmetic	0.077	No
Collins et al	1987	Pattern recognition	0.077	Yes
Collins et al	1987	Problem solving	0.077	No
Fillmore & Vogel-Sprott	1997	Number patterns recognition	0.077	Yes
Hindmarch et al	1992	Color test	0.078	No
Hindmarch et al	1992	Digit-symbol substitution	0.078	Yes
Hindmarch et al	1992	Letter recognition	0.078	No
Hindmarch et al	1992	Mental arithmetic	0.078	No
Hindmarch et al	1992	Spatial orientation	0.078	No
Hindmarch et al	1992	Sternberg	0.078	No
Hindmarch et al	1992	Sternberg	0.078	No
Kuitunen et al.	1990	Digit-symbol substitution	0.079	Yes
Kuitunen et al.	1990	Symbol copying	0.079	Yes
Nelson et al.	1986	Recall, judgement, and recognition	0.079	Yes
Oborne & Rogers	1983	Sternberg	0.079	Yes
Heisman	1997	Digit-symbol substitution	0.080	Yes
Heisman	1997	Number recognition	0.080	Yes
Heisman	1997	Word recall	0.080	Yes
Lukas et al.	1989	Digit-symbol substitution	0.080	No
Wilkinson	1995	Sternberg	0.080	No
Wilkinson	1995	Visual backward masking	0.080	Yes
Pickworth et al.	1997	Card sorting	0.096	Yes
Pickworth et al.	1997	Digit-symbol substitution	0.096	No
Pickworth et al.	1997	Letter search	0.096	No
Pickworth et al.	1997	Serial addition/subtraction	0.096	Yes

TABLE A 8

SUMMARY OF TEST RESULTS FOR COGNITIVE TASKS

Author	Year	Experimental Task	BAC	Impairment
Hindmarch et al	1992	Color test	0.100	No
Hindmarch et al	1992	Digit-symbol substitution	0.100	Yes
Hindmarch et al	1992	Letter recognition	0.100	No
Hindmarch et al	1992	Mental arithmetic	0.100	No
Hindmarch et al	1992	Spatial orientation	0.100	No
Hindmarch et al	1992	Sternberg	0.100	No
Hindmarch et al	1992	Sternberg	0.100	No
Hindmarch et al.	1991	Sternberg	0.104	No
Kennedy et al	1993	Code substitution	0.110	Yes
Kennedy et al	1993	Grammatical reasoning	0.110	No
Kennedy et al	1993	Mathematical processing	0.110	Yes
Kennedy et al	1993	Pattern discrimination	0.110	Yes
Kennedy et al	1993	Spatial orientation	0.110	Yes
Kennedy et al	1993	Sternberg	0.110	Yes
Pickworth et al.	1997	Card sorting	0.117	Yes
Pickworth et al.	1997	Digit-symbol substitution	0.117	Yes
Pickworth et al.	1997	Letter search	0.117	No
Pickworth et al.	1997	Serial addition/subtraction	0.117	Yes
Pickworth et al.	1997	Card sorting	0.139	Yes
Pickworth et al.	1997	Digit-symbol substitution	0.139	Yes
Pickworth et al.	1997	Letter search	0.139	No
Pickworth et al.	1997	Serial addition/subtraction	0.139	Yes
Hindmarch et al.	1991	Sternberg	0.142	Yes
Kennedy et al	1993	Code substitution	0.160	Yes
Kennedy et al	1993	Grammatical reasoning	0.160	No
Kennedy et al	1993	Mathematical processing	0.160	Yes
Kennedy et al	1993	Pattern discrimination	0.160	Yes
Kennedy et al	1993	Spatial orientation	0.160	Yes
Kennedy et al	1993	Sternberg	0.160	Yes

TABLE A 9

SUMMARY OF TEST RESULTS FOR PSYCHOMOTOR SKILLS

Author	Year	Experimental Task	BAC	Impairment
Mangold et al.	1996	Body balance	0.011	No
Mangold et al.	1996	Body balance	0.014	No
Pickworth et al.	1997	Circular lights	0.014	Yes
Perrine	1994	Diving	0.017	No
Cohen et al.	1987	Body balance	0.018	Yes
Kuitunen et al.	1990	Body balance	0.021	No
Mattila et al.	1992	Body balance	0.026	No
Price & Flax	1982	Drill press operation	0.028	No
Mills & Bisgrove	1983	Body sway	0.030	Yes
Mangold et al.	1996	Body balance	0.036	No
Pickworth et al.	1997	Circular lights	0.036	Yes
van Steveninck et al.	1993	Body balance	0.038	No
Kuitunen et al.	1990	Body balance	0.040	No
Mongrain	1989	Simulated raquetball	0.040	No
Perrine	1994	Diving	0.040	Yes
Schuckit	1985	Body sway	0.040	Yes
Cohen et al.	1987	Body balance	0.043	No
Mangold et al.	1996	Body balance	0.043	Yes
Cohen et al.	1987	Body balance	0.044	Yes
Price et al.	1986	Electronics assembly task	0.049	Yes
Lukas et al.	1989	Body sway	0.050	Yes
Lukas et al.	1989	Finger tapping, hand steadiness	0.050	No
Mattila et al.	1992	Body balance	0.050	No
Tianwo et al.	1995	Body balance	0.053	Yes
Lukas et al.	1989	Finger tapping, hand steadiness, body sway	0.058	No
Kennedy et al	1993	Finger tapping	0.060	Yes
Kuitunen et al.	1990	Body balance	0.060	No
Maylor & Rabbitt	1987	Video game	0.061	Yes
Lukas et al.	1989	Body sway	0.062	Yes

TABLE A 9

SUMMARY OF TEST RESULTS FOR PSYCHOMOTOR SKILLS

Author	Year	Experimental Task	BAC	Impairment
Lukas et al.	1989	Finger tapping, hand steadiness	0.062	No
Mills & Bisgrove	1983	Body sway	0.062	Yes
Pickworth et al.	1997	Circular lights	0.062	Yes
Price & Flax	1982	Drill press operation	0.062	Yes
Price et al.	1986	Electronics assembly task	0.069	Yes
Lukas et al.	1989	Body sway	0.070	Yes
Lukas et al.	1989	Finger tapping, hand steadiness	0.070	No
Perrine	1994	Diving	0.071	Yes
Laberg & Löberg	1989	Hand steadiness and coordination	0.073	Yes
Lukas et al.	1989	Body sway	0.075	No
Lukas et al.	1989	Finger tapping, hand steadiness	0.075	No
Mattila et al.	1992	Body balance	0.076	Yes
Azcona et al.	1995	Finger tapping	0.078	No
Kuitunen et al.	1990	Body balance	0.079	No
Lukas et al.	1989	Body sway	0.080	Yes
Lukas et al.	1989	Finger tapping, hand steadiness	0.080	No
Schuckit	1985	Body sway	0.081	Yes
Price & Flax	1982	Drill press operation	0.092	Yes
Price et al.	1986	Electronics assembly task	0.093	Yes
Pickworth et al.	1997	Circular lights	0.096	Yes
Perrine	1994	Diving	0.097	No
Perrine	1994	Diving	0.100	Yes
Kennedy et al	1993	Finger tapping	0.110	Yes
Pickworth et al	1997	Circular lights	0.117	Yes
Mongrain	1989	Simulated raquetball	0.120	No
Perrine	1994	Diving	0.123	Yes
Pickworth et al	1997	Circular lights	0.139	Yes
Kennedy et al	1993	Finger tapping	0.160	Yes

TABLE A 10

SUMMARY OF TEST RESULTS FOR CHOICE RT

Author	Year	Experimental Task	BAC	Impairment
Millar et al.	1992	RT to 1 of 5 circles	0.014	No
Hindmarch et al	1992	Report wich of 6 lights turned on and off	0.020	No
MacArthur & Sekuler	1982	Choice RT	0.020	No
MacArthur & Sekuler	1982	Choice RT	0.020	Yes
Hindmarch et al.	1991	Estinguish 1 of 6 lights	0.027	No
Maylor et all.	1987	Choice RT to video characters	0.029	No
Jääskeläinen et al.	1995	RT to auditory stimuli	0.030	No
Millar et al.	1992	RT to 1 or 5 circles	0.030	No
Colrain at al.	1993	RT to presence of vertical check pattern	0.032	Yes
Finnigan et al.	1995	Report changes in 1 of 5 circles	0.040	No
Gengo et al.	1990	Report wich of 6 lights turned on and off	0.040	Yes
Colrain at al.	1993	RT to presence of vertical check pattern	0.043	Yes
Antebi	1982	Choice RT	0.045	Yes
Vermeeren & O'Hanlon	1998	Choice RT with distracting cues	0.045	Yes
Hindmarch et al	1992	Report wich of 6 lights turned on and off	0.052	No
Finnigan et al.	1995	Report changes in 1 of 5 circles	0.056	No
Jääskeläinen et al.	1995	RT to auditory stimuli	0.060	No
Kennedy et al	1993	Four-choice RT	0.060	Yes
MacArthur & Sekuler	1982	Choice RT	0.060	No
MacArthur & Sekuler	1982	Choice RT	0.060	Yes
Millar et al.	1992	RT to 1 or 5 circles	0.060	No
Jääskeläinen et al.	1996	Choice RT with auditory distraction	0.062	Yes
Finnigan et al.	1995	Report changes in 1 of 5 circles	0.063	No
Hindmarch et al.	1991	Estinguish 1 of 6 lights	0.066	Yes
Maylor et al.	1992	2-, 4-, or 8-choice RT	0.067	Yes
Colrain at al.	1993	RT to presence of vertical check pattern	0.068	Yes
Mulvihill et al.	1996	Choice RT with inhibitory control	0.073	Yes
Finnigan et al.	1995	Report changes in 1 of 5 circles	0.075	Yes
Collins et al	1987	RT to onset of one of 5 lights	0.077	Yes

TABLE A 10

SUMMARY OF TEST RESULTS FOR CHOICE RT

Author	Year	Experimental Task	BAC	Impairment
Hindmarch et al	1992	Report wich of 6 lights turned on and off	0.078	Yes
Colrain at al.	1993	RT to presence of vertical check pattern	0.096	Yes
Hindmarch et al	1992	Report wich of 6 lights turned on and off	0.100	Yes
Hindmarch et al.	1991	Estinguish 1 of 6 lights	0.104	Yes
Kennedy et al	1993	Four-choice RT	0.110	Yes
Maylor et all.	1987	RT to video characters	0.130	Yes
Hindmarch et al.	1991	Estinguish 1 of 6 lights	0.142	Yes
Kennedy et al	1993	Four-choice RT	0.160	Yes

TABLE A 11

SUMMARY OF TEST RESULTS FOR SIMPLE RT

Author	Year	Experimental Task	BAC	Impairment
Heishman et al.	1997	Simple RT	0.005	No
Cohen et al.	1987	Respond to onset of visual clock	0.018	No
Heishman et al.	1997	Simple RT	0.025	No
Wang et al.	1992	Respond to light onset	0.025	No
Wang et al.	1992	Respond to light onset	0.030	No
Cohen et al.	1987	Respond to onset of visual clock	0.043	Yes
Cohen et al.	1987	Respond to onset of visual clock	0.044	Yes
Wang et al.	1992	Respond to light onset	0.047	Yes
Wang et al.	1992	Respond to light onset	0.050	No
Baker	1985	RT to auditory or visual stimulus	0.055	Yes
Wang et al.	1992	Respond to light onset	0.055	No
Wang et al.	1992	Respond to light onset	0.060	Yes
Wang et al.	1992	Respond to light onset	0.065	No
Wang et al.	1992	Respond to light onset	0.070	No
Wang et al.	1992	Respond to light onset	0.075	Yes
Azcona et al	1995	Respond to single stimulus onset	0.078	Yes
Heishman et al.	1997	Simple RT	0.080	No
Wang et al.	1992	Respond to light onset	0.090	No
Wang et al.	1992	Respond to light onset	0.095	No
Wang et al.	1992	Respond to light onset	0.100	Yes

TABLE A 12

SUMMARY OF TEST RESULTS FOR CFF

Author	Year	Experimental Task	BAC	Impairment
Millar et al.	1992	Critical flicker fusion	0.014	No
Hindmarch et al	1992	Critical flicker fusion	0.020	No
Kuitunen et al.	1990	Critical flicker fusion	0.021	No
Hindmarch	1991	Critical flicker fusion	0.027	No
Millar et al.	1992	Critical flicker fusion	0.030	No
Kuitunen et al.	1990	Critical flicker fusion	0.040	No
Hindmarch et al	1992	Critical flicker fusion	0.052	No
Jansen et al.	1985	Critical flicker fusion	0.054	No
Baker	1985	Critical flicker fusion	0.055	No
Kuitunen et al.	1990	Critical flicker fusion	0.060	No
Millar et al.	1992	Critical flicker fusion	0.060	No
Hindmarch	1991	Critical flicker fusion	0.066	No
Azcona et al.	1995	Critical flicker fusion	0.078	No
Hindmarch et al	1992	Critical flicker fusion	0.078	No
Kuitunen et al.	1990	Critical flicker fusion	0.079	No
Hindmarch et al	1992	Critical flicker fusion	0.100	Yes
Hindmarch	1991	Critical flicker fusion	0.104	Yes
Hindmarch	1991	Critical flicker fusion	0.142	Yes

TABLE A 13

SUMMARY OF TEST RESULTS FOR AFTEREFFECTS

Author	Year	Experimental Task	BAC	Impairment
Cohen at al.	1987	Adaptive tracking	0.000	No
Cohen et al.	1987	Body balance	0.000	No
Cohen et al.	1987	Eye movements	0.000	No
Cohen et al.	1987	Simple visual RT	0.000	No
Kennedy et al	1993	Delta	0.000	No
Kuitunen et al.	1990	Body balance	0.000	No
Kuitunen et al.	1990	Coordination of extraocular muscles	0.000	No
Kuitunen et al.	1990	Critical flicker fusion	0.000	No
Kuitunen et al.	1990	Digit-symbol substitution	0.000	No
Kuitunen et al.	1990	Symbol copying	0.000	No
Kuitunen et al.	1990	Tracking error severity index	0.000	No
Morrow et al.	1990	Flight simulator (severe altitude errors, summary score)	0.000	No
Pickworth et al.	1997	Card sorting	0.000	No
Pickworth et al.	1997	Circular lights	0.000	No
Pickworth et al.	1997	Digit-symbol substitution	0.000	No
Pickworth et al.	1997	Letter search	0.000	No
Pickworth et al.	1997	Serial addition/subtraction	0.000	No
Roehrs et al	1994b	Divided attention task	0.000	No
Roehrs et al	1994b	MSLT	0.000	Yes
Roehrs et al.	1989	MSLT	0.000	Yes
Ross & Mughni	1995	Detection of angular motion	0.000	Yes
Taylor et al.	1994	Flight simulator	0.000	Yes
Taylor et al.	1996	Flight simulator	0.000	No
Yesavage et al.	1986	Flight simulator	0.000	Yes
Yesavage et al.	1994	Flight simulator	0.000	Yes

Appendix B

Data Comparison Between Moskowitz and Robinson (1988) and Moskowitz and Fiorentino (1999)

Impairment in experimental studies was found more frequently at lower BACs in this review than in Moskowitz and Robinson (1988). This can be clearly seen across all behavioral areas.

In the following section, we examined the number of studies for each behavioral area from Moskowitz and Robinson (1988) and the current review. The results from Moskowitz and Robinson (1988) have been rearranged to fit into the BAC breakdown of the current study (i.e., ending in zero rather than 9). Tables B1 and B2 report the number of studies reporting impairment by lowest BAC at which impairment was found for the Moskowitz and Robinson (1988) and the current study, respectively.

Note that here we are looking at the number of studies at each behavioral area. Most studies are represented in more than one behavioral area, thus the total number of behavioral areas by study increases to 221 and 150 for Moskowitz and Robinson (1988) and the current review, respectively. This is less than the number of BACs at which the behavioral areas are examined in section 3.2. and figures 3 and 4.

TABLE B 1

NUMBER OF STUDIES WITHIN EACH BEHAVIORAL AREA BY THE LOWEST BAC AT WHICH IMPAIRMENT WAS FOUND (MOSKOWITZ AND ROBINSON,1988)

Domain	BAC (g/dl)										
	0.001 to 0.009	0.010 to 0.019	0.020 to 0.029	0.030 to 0.039	0.040 to 0.049	0.050 to 0.059	0.060 to 0.069	0.070 to 0.079	0.080 to 0.089	≥ 0.090	Total
Reaction Time (RT)	0	0	0	2	4	7	1	11	3	17	**45**
Tracking	0	0	2	3	3	7	4	6	3	2	**30**
Concentrated Attention	0	0	0	0	0	0	3	1	1	2	**7**
Divided Attention	0	0	2	2	2	3	2	2	0	2	**15**
Information Processing	0	0	1	0	1	2	3	8	3	6	**24**
Visual Functions	0	1	0	3	1	6	1	4	3	9	**28**
Perception	0	0	2	0	2	1	0	4	4	9	**22**
Psychomotor	0	0	1	2	3	3	4	0	2	13	**28**
Driver Performance	0	0	0	4	2	1	1	3	1	10	**22**
TOTAL	**0**	**1**	**8**	**16**	**18**	**30**	**19**	**39**	**20**	**70**	**221**
Cumulative %	**0%**	**0%**	**4%**	**11%**	**19%**	**33%**	**42%**	**59%**	**68%**	**100%**	

TABLE B 2

NUMBER OF STUDIES WITHIN EACH BEHAVIORAL AREA BY THE LOWEST BAC AT WHICH IMPAIRMENT WAS FOUND (MOSKOWITZ & FIORENTINO, 1999)

Domain	BAC (g/dl)										
	0.001 to 0.009	0.010 to 0.019	0.020 to 0.029	0.030 to 0.039	0.040 to 0.049	0.050 to 0.059	0.060 to 0.069	0.070 to 0.079	0.080 to 0.089	≥ 0.090	Total
Cognitive Tasks	0	1	1	3	5	2	8	6	0	1	27
Critical Flicker Fusion	0	0	0	0	0	0	0	0	0	2	2
Divided Attention	1	2	2	3	2	2	1	1	2	1	17
Driving	2	1	2	1	5	4	3	2	2	1	23
Perception	0	0	0	1	2	3	1	1	0	1	9
Psychomotor	0	2	0	1	4	2	3	2	0	0	14
Reaction Time - Complex	0	0	1	1	2	0	5	4	0	1	14
Reaction Time - Simple	0	0	0	0	2	1	0	1	0	0	4
Tracking	0	1	0	1	0	2	1	1	0	1	7
Vigilance	0	0	0	5	1	2	0	0	1	0	9
Visual Functions	0	0	1	2	6	1	3	3	2	0	18
Wakefulness	0	2	1	2	0	1	0	0	0	0	6
TOTAL	**3**	**9**	**8**	**20**	**29**	**20**	**25**	**21**	**7**	**8**	**150**
Cumulative %	**2%**	**8%**	**13%**	**27%**	**46%**	**59%**	**76%**	**90%**	**95%**	**100%**	