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EFFECTS OF ALCOHOL ON COMPLEX PERFORMANCE

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I. Introduction.

Both field surveys of accidents and laboratory studies have been interpreted to show that human performance is adversely affected by blood alcohol levels as low as 50 mg.%. In a study of fatal, single-vehicle automobile accidents, Haddon and Brodess[5] found that half of the drivers had blood alcohol levels in excess of 150 mg.% at the time of death. Another 20% of the drivers showed levels between 50 and 150 mg.%.

Harper and Albers[6], in a survey of general aviation fatal accidents found that in 35.4% of the cases the pilot had a blood alcohol level greater than 15 mg.%. Dille and Morris[4] reported blood alcohol levels greater than 30 mg.% in 19.8% of the pilots in another study of fatal general aviation accidents.

Bjerver and Goldberg[2] used a special track designed to measure ability to operate a car within close limits. Such maneuvers as parallel parking, driving out of a garage, and turning around on a narrow roadway were required. The time for skilled drivers to perform the tests correctly was significantly lengthened when the subjects were at blood alcohol levels of about 40 mg.%.

Aksnes[1] required experienced subjects to fly a Link trainer over a U-shaped course involving several changes in heading, altitude, and airspeed. A measure of the combined error in these three parameters showed that a significant loss in overall flying proficiency was produced at a blood alcohol level of 50 mg.%.

Poorer performance under relatively low levels of blood alcohol has also been found with single tasks. Using a one dimensional pursuit tracking task with a steering wheel control, Loomis and West[7] reported a clear loss in time-on-target at a blood alcohol level of 68 mg.%. This finding was confirmed by Mortimer[8] using the same task. Carpenter[3] found a significant, though small, increase in response latencies to a visual stimulus at 70 to 80 mg.% blood alcohol. Pearson[10] reported decrements in monitoring performance and reaction time but not in tracking or arithmetic performance at 85 mg.% blood alcohol.

The purpose of the present investigation was to examine the effects of moderately high levels of blood alcohol on complex performance. The amount of alcohol ingested by the subjects was to be clearly high enough that, on the basis of the literature, at least some tasks would be expected to reveal decrements. The primary difference between the present study and previous investigations is that the time-shared performance of several tasks would be required and different levels of workload would be used. A second purpose of the study was to examine the tasks and task combinations comprising the performance battery as regards their sensitivity to a variable that would be expected to have an adverse effect on performance.

II. Method.

Subjects. Nine paid male subjects, all in their early twenties, were tested in this experiment. Six were Air Force enlisted men and three were graduate students from the University of Oklahoma. These subjects served concurrently in another experiment which involved rotational and caloric stimulation of vestibular mechanisms. Immediately before each baseline session and the alcohol session, the subjects experienced a period of rotational vestibular stimulation.

Experimental tasks. The tasks constituting Model 1 of the Tracking and Monitoring Task described by Pearson[9] were used to provide the performance measures. Two active tasks were presented—compensatory tracking and mental arithmetic. These tasks are generally the primary focus of the subject's attention. The passive tasks required (1) monitoring of a pair of meters, (2) choice reaction time to a pair of red and green lights, and (3) reaction time to a peripherally-located amber light.

The tracking task display was a round oscilloscope screen, 12 cm. in diameter located in the upper center of the panel with horizontal and vertical lines bisecting the screen to define the center. The subject's task was to keep an illuminated dot approximately 1 mm. in diameter centered on the screen at the intersection of the two lines. He did this by manipulating a small control stick with his right hand. The forcing function for the tracking task was controlled by a stepping switch which advanced every 4 seconds. Each advance of the stepper introduced a new random bias into the oscilloscope display. A movement of the control stick of approximately 25° from vertical was required to compensate for the maximum deflection caused by the forcing function. Forward stick movement moved the dot down; movement of the stick to the right moved the dot to the right. Performance on tracking was scored by an analog computer with individual scores in volts on an arbitrary scale for horizontal and vertical integrated absolute error and for horizontal and vertical integrated error squared. The error squared measures were converted to RMS (root mean square) error for purposes of analysis.

The mental arithmetic task required the addition of two 2-digit numbers and subtraction of a third. The numbers were presented in succession on three, adjacent, rear-projection readouts on the performance panel. A buzzer came on with the presentation of each number and remained on until the subject responded to that number. The subject responded to the first two numbers by pressing a button beneath the appropriate readout. Upon the introduction of the third number, the subject entered his answer on a keyboard and pressed a "solution button" to indicate that he had solved the problem. Solution time was measured from the presentation of the third number until the subject pressed the solution button. Subjects were also scored for accuracy of response, but feedback as to accuracy was not given to the subjects. Problems were presented at a maximum average rate of three per minute. All subjects handled this rate readily during the baseline testing session.

The three passive tasks were choice reaction time, meter monitoring, and simple reaction time to a peripherally located amber light. During the testing session the subject was instructed to keep his left hand on a ready key (located at the front of the console) except when responding to one of the tasks. For the choice reaction task, the subject was required to respond to a red light by pressing a red telegraph key located below the light; he responded to a green light by pressing a green key. Two measures were taken for this task. Reaction time was measured directly from the time the light came on until the subject lifted his hand from the ready key.

The total response time was measured from the onset of the light until the response key was pressed. Movement time was derived by subtracting reaction time from total time. (No analysis was made of the total time measure because an earlier study using the same task had indicated no new information was contained in this measure that was not already available in the reaction measures.) Signals were introduced on this task at a rate of 12 per 5 minutes. The sequence of intersignal intervals was established by random selection from a distribution of intervals ranging from .3 to .7 minutes.

The meter monitoring task required the subject to monitor the state of two meters, one on the left side and one on the right side of the tracking display. The pointers were normally in a horizontal position. When a signal was introduced, one of the meters would drift slowly, either up or down, reaching a maximum deflection of approximately 20° in 7.5 to 8 seconds. At the end of this period, the meter (if not responded to) would return rapidly to center. The subject responded to a meter deflection by pressing the appropriate one of two buttons located at the lower left corner of his panel. If the subject responded correctly before the end of the 8-second presentation period, the pointer would "freeze" at its current position and a light would come on over the affected meter. At the end of the signal presentation period, the meter returned to its normal state and the light went out. The meter deflections were programmed so that there were either seven or eight meter events per 5 minutes.

The amber light was located at the lower left-hand corner of the subject's panel. It was programmed to produce either one, two, or three signals per 5-minute interval. The subject responded to the illumination of the amber light by depressing a button mounted on the top of the tracking control. The amber light and tracking tasks were the only tasks involving the right hand.

Procedure. Each subject was tested for one session at approximately the same time each day for five successive days. Each testing session consisted of three, 15-minute trials with a break of approximately 2 minutes between trials. During these trials the three passive tasks operated continuously. Three workload conditions were presented as follows: The first 5 minutes involved tracking (workload A); the second 5 minutes (workload B) involved arithmetic; and during the final 5 minutes (workload C) tracking and arithmetic were performed concurrently. During the 5 minutes that the subject was not required to track, the tracking display remained on and responsive to the control, but the forcing function and scoring were turned off. The first three daily sessions were devoted to training and practice. Data from the fourth session were used as a baseline measure, and the test session under the alcohol condition was held the fifth day.

About two hours before the test session, subjects were given 2.5 ml. per kg. of body weight of an alcoholic beverage.* The alcoholic beverage was mixed with a quantity of orange juice sufficient to bring the total amount of liquid ingested to 700 ml. Subjects one through six had alcohol determinations made on samples taken 30 minutes, 1, 2, and 5 hours after ingestion of alcohol. However, because of a slight change in scheduling of the vestibular stimulation experiment, the last three subjects had blood alcohol tests on samples taken at 30 minutes, 1, and 4 hours. The estimated blood alcohol level at the start of testing for these latter three subjects was computed as follows: First, the mean hourly rate of decline in blood alcohol was computed for all subjects using the 1-hour and 5-hour tests for the first six subjects and the 1-hour and 4-hour tests for the last three. Using this mean hourly rate of change (11.25 mg.%/hr), separate estimates of the 2-hour blood alcohol level for the last three subjects were made by working forward from the 1-hour test and backward from the 4-hour test. The mean of the two figures was used as the 2-hour blood alcohol level.

Data analysis. Each measure of performance was analyzed separately with three sources of variance being examined; namely, subjects, workload and alcohol (vs. baseline). An additional source of variance, trials, was included for arithmetic solution time, arithmetic accuracy, and meter detection times. Because of lost data on one or more trials for the other measures, the unit of analysis in those cases was the session mean for a given workload condition. The passive tasks were presented under all conditions; thus there were three workloads on these tasks. The active tasks were presented under two workloads, A and C for tracking and B and C for arithmetic.

* The beverage used was Tvarscki, 100 proof vodka. Thus, in terms of alcoholic content, the dosage was approximately equivalent to 1 g. of ethyl alcohol/kg of body weight.

III. Results.

Blood alcohol levels. The mean blood alcohol level at the beginning of testing was 102 mg.%. The maximum value for any subject was 124 mg.%; the minimum was 84 mg.% (Table 1).

TABLE 1. Blood alcohol levels in mg.%

Subject Number	Minutes after Ingestion				
	30	60	180	240	300
1	94	120	103	----	61
2	92	114	110	----	74
3	103	125	124	----	82
4	100	122	96	----	68
5	99	115	103	----	60
6	58	108	98	----	54
7	43	104	*92	68	----
8	30	79	*81	71	----
9	80	130	*114	86	----
Mean			102		

*Values interpolated from 60- and 240-minute determinations.

The alcohol, in conjunction with the vestibular stimulation, produced feelings of nausea in three subjects prior to the beginning of the alcohol test session. One of these subjects vomited and the other two indicated a moderate degree of discomfort. However, the effect was transitory and the subjects reported that they had recovered when testing began. Other than this, joint alcohol/vestibular effects on the general behavior of the subjects were not apparent.

Workload. Means for each workload condition for the various measures of performance are shown in Tables 2, 3, and 4. Summary tables for the analyses of variance are presented in Tables 5 through 10 in the Appendix.

TABLE 2. Monitoring Performance

(Mean Times in Seconds)

		Workload*			
		A	B	C	Total
Reaction Time	Baseline	.69	.82	.80	.77
	Test	.76	1.10	1.04	.97
	Total	.72	.96	.92	
Movement Time	Baseline	.54	.52	.58	.55
	Test	.46	.65	.68	.59
	Total	.50	.58	.63	
Simple Reaction Time	Baseline	1.08	1.55	1.28	1.30
	Test	1.14	1.84	1.28	1.42
	Total	1.11	1.69	1.28	
Meter Detection Time	Baseline	3.24	3.66	3.49	3.47
	Test	3.64	4.37	3.98	4.00
	Total	3.44	4.02	3.74	

*A—Monitoring and Tracking
B—Monitoring and Arithmetic
C—Monitoring, Tracking and Arithmetic

TABLE 3. Arithmetic Performance

		Workload*		
		B	C	Total
Solution Time in Seconds	Baseline	5.15	4.69	4.92
	Test	4.96	4.47	4.72
	Total	5.06	4.58	
Percent Correct	Baseline	90.7	90.3	90.5
	Test	88.8	87.5	88.1
	Total	89.7	88.9	

*B—Arithmetic and Monitoring
C—Arithmetic, Monitoring and Tracking

Movement time on the choice reaction time task was significantly affected by workload (P<.05; Table 5), but the effect was not large. The difference between the tracking and the arithmetic plus tracking conditions was only .13 seconds. Means for this and all of the other measures are shown in Table 2. The reaction time measure was not significantly affected by workload (P<.10; Table 5) even though the largest difference (condition A versus condition B) was almost twice as great as the largest difference for movement time (.24 seconds as compared to .13 seconds).

Simple reaction time (the amber light) was significantly affected by workload (P<.01; Table 6). The largest difference, .58 seconds, was between workload conditions A and B, with faster responses being associated with condition A, the tracking plus monitoring condition. The difference between condition C and condition B was .41 seconds; faster response times occurred under the heavier workload condition.

TABLE 4. Tracking Performance

(Error Measures in Volts [Arbitrary Scales])

		Workload*		
		A	C	Total
Horizontal Integrated Absolute Error	Baseline	48.02	82.67	65.35
	Test	62.81	105.70	84.25
	Total	55.42	94.19	
Vertical Integrated Absolute Error	Baseline	42.93	64.79	53.86
	Test	48.08	84.50	66.29
	Total	45.51	74.64	
Horizontal RMS Error	Baseline	3.27	6.12	4.70
	Test	4.16	6.99	5.57
	Total	3.72	6.55	
Vertical RMS Error	Baseline	2.77	4.21	3.49
	Test	3.24	5.66	4.45
	Total	3.00	4.93	

*A—Tracking and Monitoring
C—Tracking, Monitoring and Arithmetic

Both integrated absolute error and RMS error showed workload to have significant effects on tracking in the horizontal dimension (P<.01 in both cases; Tables 7 and 8). Only RMS error showed a significant effect of workload with respect to tracking in the vertical dimension (P<.05; Table 8).

Neither solution time nor percent correct on the arithmetic task were affected by workload (Table 9), nor was detection time on the meter task (Table 10).

Alcohol. Two of the measures of monitoring performance showed an effect of alcohol (Table 2). Reaction time on the choice reaction time task increased by .30 seconds under the alcohol condition (P<.05; Table 5), and detection time on the meter task increased by .53 seconds (P<.01; Table 10). The other two measures of monitoring performance, movement time on choice reaction and simple reaction time, were not affected (Tables 5 and 6). However, the alcohol by workload interaction approached significance for movement time (P<.10).

Neither solution time nor accuracy on the arithmetic task were affected by alcohol (Table 9).

Tracking in the horizontal dimension showed an alcohol effect as measured by integrated absolute error ($P<.01$; Table 7) but not as measured by RMS error ($.10>P>.05$; Table 8). In the case of absolute error, there was a substantial, though not significant, interaction between alcohol and workload ($.10>P>.05$; Table 7).

Tracking in the vertical dimension was significantly affected as measured by both integrated absolute error and RMS error ($P<.05$ in both cases; Tables 7 and 8). The interaction between alcohol and workload was significant in the case of RMS error ($P<.05$; Table 8) but not in the case of integrated absolute error ($.10>P>.05$; Table 7).

TABLE 5.—Choice Reaction Time Task
(Analysis of Variance)

	Reaction Time				Movement Time			
	df	MS	F	P	df	MS	F	P
Subjects (S)	8	1.263			8	.215		
Alcohol Condition (C)	1	.520	6.41	<.05	1	.033	1.01	
Workload (W)	2	.289	2.93	<.10	2	.081	4.12	<.05
SC	8	.081			8	.033		
SW	16	.098			16	.020		
CW	2	.053	2.15		2	.059	2.77	>.10
SCW	16	.024			16	.021		

TABLE 6. Simple Reaction Time
(Analysis of Variance)

	df	MS	F	P
Subjects (S)	8	2.22		
Alcohol Condition (C)	1	.18	1.5	
Workload (W)	2	2.63	7.73	<.01
SC	8	.12		
SW	16	.34		
CW	2	.12	.20	
SCW	16	.49		

TABLE 7.—Integrated Absolute Error in Tracking
(Analysis of Variance)

	Horizontal Dimension				Vertical Dimension			
	df	MS	F	P	df	MS	F	P
Subjects (S)	8	4,832			8	3,923		
Alcohol Condition (C)	1	3,216	17.19	<.01	1	1,390	6.49	<.05
Workload (W)	1	13,529	13.03	<.01	1	7,641	5.03	<.10
SC	8	187			8	214		
SW	8	1,038			8	1,517		
CW	1	153	4.65	<.10	1	477	5.18	<.10
SCW	8	33			8	91		

Table 8.—Root Mean Square Error in Tracking
(Analysis of Variance)

	Horizontal Dimension				Vertical Dimension			
	df	MS	F	P	df	MS	F	P
Subjects (S)	8	14.596			8	13.6989		
Alcohol Condition (C)	1	6.915	4.25	<.10	1	8.2560	9.64	<.05
Workload (W)	1	72.431	24.86	<.01	1	33.4855	8.26	<.05
SC	8	1.626			8	.8563		
SW	8	2.914			8	4.0553		
CW	1	.001	.003		1	2.1610	5.78	<.05
SCW	8	.298			8	.3735		

Table 9.—Arithmetic Performance
(Analysis of Variance)

	Solution Time				Percent Correct			
	df	MS	F	P	df	MS	F	P
Subjects (S)	8	71.95			8	808.30		
Alcohol Condition (C)	1	1.15	1.62		1	149.34	.51	
Workload (W)	1	6.13	2.30		1	17.76	.41	
Testing Interval (T)	2	2.06	1.61		2	104.21	1.25	
SC	8	.71			8	290.39		
SW	8	2.67			8	43.54		
ST	16	1.28			16	83.31		
CW	1	.01	.06		1	4.82	.06	
CT	2	.54	.97		2	199.76	2.93	
WT	2	.78	1.09		2	179.22	2.67	
SCW	8	.16			8	76.27		
SCT	16	.55			16	68.17		
SWT	16	.71			16	67.01		
CWT	2	.49	1.21		2	74.90	1.47	
SCWT	16	.41			16	50.91		

Table 10. Meter Detection Times
(Analysis of Variance)

	df	MS	F	P
Subjects (S)	8	34.27		
Alcohol Condition (C)	1	11.45	32.71	<.01
Workload (W)	2	4.41	2.61	
Testing Interval (T)	2	.66	1.50	
SC	8	.35		
SW	16	1.69		
ST	16	.44		
CW	2	.32	.83	
CT	2	.18	.50	
WT	4	.21	.32	
SCW	16	.39		
SCT	16	.35		
SWT	32	.65		
CWT	4	.18	.77	
SCWT	32	.24		

IV. Discussion.

Workload effects. The effects of the different workload conditions on movement time in responding to the choice reaction time task were probably a result of some sort of perceptual-motor conflict. First, when problems were being presented on the arithmetic task, at least occasionally, a red or green light would be illuminated at the same time. This might very well have generated a momentary conflict situation sufficient to account for at least part of the increased movement time associated with the two task combinations involving arithmetic. A second factor was introduced by the nature of the programming of the choice reaction time task. As noted in the procedure section, the subject was required to keep his left hand on a ready switch when not responding to one of the tasks with that hand. If the programming equipment attempted to illuminate a red or green light at a time when the ready switch was not depressed, *that signal* would be "stored" until such time as the subject returned his hand to the ready switch. At that point, depression of the switch in effect turned on the light selected by the programming mechanism to be illuminated. Since the subject's hand was off the switch a substantial portion of time when he was solving arithmetic problems, a number of signals were introduced in this manner. Thus, a very plausible second explanation of the increases in movement time would be that movements immediately following the return of the subject's hand to the switch would be slower than those when the hand was initially in a resting position on the switch. The increase in reaction time under the two arithmetic workload conditions, though not significant, is compatible with this interpretation.

The increase in the response times to the amber light during arithmetic performance is probably directly a function of where the subject was focusing his attention. Since the arithmetic problems are presented by means of displays on the right side of the panel and the response buttons are also located there, that is where the subject tends to look when arithmetic performance is required. Under condition B, arithmetic plus monitoring, the only reason for the subject to look away from the arithmetic task mechanisms is to scan the remainder of the panel. Thus, during this workload condition, he generally does not see the amber light as it comes on except between problems on the arithmetic task. The light is in the periphery when he is looking at the arithmetic mechanisms and it does not have sufficient attention value for him to see it. When both tracking and arithmetic are being performed, the subject is required to divide his attention between the two. The location of the amber light in relation to the focus of the subject's attention when he is tracking is such that the subject can readily see the light. This would seem to account for the intermediate position of the heavier workload condition with respect to the simple reaction time measure; the tracking task forces him to look a greater proportion of the time at a section of the panel where he can see the amber light.

The effects of workload on the tracking task can be explained in a straightforward manner. When the subject is working arithmetic problems, it takes him an average of about 4.5 seconds to compute and enter his answer after being given the third number. Much of this time the subject does not look at the tracking display. During the presentation of each of the first two numbers of the problem, the subject also looks away from the tracking display to determine what the number is and to acknowledge that he has seen it. Thus, of the approximately 20 seconds per arithmetic problem, the subject looks away from the tracking display for perhaps as much as a third of the time. In contrast, when the subject is concerned with tracking and only the monitoring tasks, only brief glances at the monitoring displays are required to keep up with those tasks. The only aspect of this finding that was at all surprising is the fact that the workload effect was not significant in the case of integrated absolute error in the vertical dimension. This presumably was a result of the substantial variability in the specific strategies adopted by different subjects in time-sharing the tracking and arithmetic tasks.

Another factor that probably contributed to the magnitude of the workload effect with respect to the horizontal dimension was that a certain amount of cross-coupling between the two arms occurred when arithmetic and tracking were performed concurrently. When the subject responded to the arithmetic task, he was required to reach across the panel with his left hand to a position approximately in front of the tracking control. In making this movement, there is a marked tendency for the subject's body to move laterally, and, in so doing, he inadvertently introduces inputs to the tracking task. These inputs are much more likely to be in a plane that affects the horizontal dimension rather than the vertical. The subject can anchor his wrist on the table so that fore/aft movements of his arm are virtually eliminated. Slight rotational movements of the wrist (which would affect the horizontal but not the vertical dimension) are much more difficult to eliminate.

Workload did not affect the performance of the arithmetic task. The only suggestive effect was that the mean response time was shorter (though not significantly—Table 3) for the tracking plus arithmetic condition. The most likely explanation for this lack of effect is that subjects placed a relatively high subjective priority on the arithmetic task and tended to "protect" their performance of this task.

Alcohol effects. The increase in choice reaction time under the alcohol condition is consistent with previous research findings. In fact, a lack of an effect would have been quite surprising since Carpenter[3] found significant increases in reaction time at a somewhat lower blood alcohol level (70 to 80 mg.% as compared to 102 mg.%). The fact that movement time was not affected suggests that the alcohol caused a deterioration in some sort of central attentional or decision process rather than a direct alteration of the subject's neuromuscular system. However, if this is in fact the case, the inference applies only to tasks in which the motor response, once initiated, does not involve any particular degree of precision in its execution.

The increase in detection times for the meter signals is in line with the results reported by Pearson[10] with the same task. The response required to indicate detection of a meter did not require precision. Thus, if the movement time data on the choice reaction time task are extrapolated to the meter task (an admittedly tenuous procedure) then it could be inferred that these decrements are reflective of a change in an attentional process. The inference is supported by the fact that the magnitude of the increase, .53 seconds, is more than twice as great as the combined increases in reaction time and movement time for the choice reaction time task.

The absence of an effect on the amber light task was also a finding of Pearson.[10] As shown by the means for this task in Table 2, the variability across the three task combinations was rather large, and, hence, the error variance associated with the statistical test for the alcohol effect was also rather large. This variability was undoubtedly also a product of the fact that signals occurred only infrequently on this task (approximately two signals per 5-minute period) and there was no alerting signal as is the case with the typical laboratory study of displays reaction time.

Perhaps the most interesting outcome of this study was the fact that mental arithmetic performance was not impaired by alcohol. We offer two possible explanations. First, the arithmetic task was basically not very difficult and the subjects had been given substantial practice. Second, there is good reason to believe that the subjects placed a relatively higher priority on doing the arithmetic because this was a task that they clearly understood and it involves an intellectual skill that most people consider to be rather important. Thus, the subjects presumably diverted a sufficient proportion of their mental capacities to the performance of this task to assure that their performance would not suffer. The fact that the different workloads affected tracking but did not affect arithmetic under both the baseline and the alcohol conditions tends to support the "priorities hypothesis." Thus, the demands of this particular arithmetic task are apparently not great enough, even at rather high blood alcohol levels, to preclude the subject's maintaining his performance by increased concentration. Of course, it is also possible, though we consider it unlikely, that alcohol has no effect on processes such as simple mental arithmetic.

Our data do not permit any clear-cut description of the manner in which alcohol affected tracking performance. An immediate question arises from the fact that we found an effect of alcohol on tracking whereas Pearson[10], using the same basic tasks at only a slightly lower blood alcohol level, found none. The first and probably most important difference between the two studies is that we included a condition involving a much heavier workload than that used by Pearson. His subjects were concerned only with the two meters and the amber light while tracking. For our tracking-only condition, we added the choice reaction time to the tasks he used and the arithmetic task was added for our heavy workload condition. Second, although we do not have details on Pearson's tracking task, there is good reason to believe that it was substantially more difficult than ours. Thus, with the amounts of training given our subjects, their levels of skill probably resulted in somewhat lower variability than was the case for Pearson's subjects.

In an attempt to further examine the workload hypothesis as an explanation of the discrepancy between Pearson's[10] results and ours, we analyzed the simple effects of alcohol for each of the two levels of workload under which the tracking task was performed. The results of these tests showed that for no measure was tracking *significantly* affected by the alcohol when tracking was performed by itself. (Actually, the t-test for the horizontal absolute error fell just short of significance; $t_{.05}=2.306$, and the obtained t was 2.293.) In all three cases in which an over-all effect of alcohol was found, a significant t was found for tracking when performed concurrently with arithmetic. (As noted under Results and as shown in Tables 7 and 8, alcohol workload interaction was significant ($P<.05$) for vertical RMS error and borderline ($P<.10$) for horizontal and vertical absolute error.)

Thus, a decrease in the ability of the subject to time-share the performance of tasks requiring the exercise of different psychological functions may be the most important detrimental effect of alcohol on trained subjects. Motor effects may be somewhat less important.

Finally, it is necessary to comment briefly on the possible implications of the fact that our subjects were also serving in a study on the effects of alcohol on vestibular functions. Although all subjects reported that they had recovered from any discomfort produced by riding the rotating chair before our testing began, one should perhaps exercise caution in accepting the statements of subjects whose mean blood alcohol levels are 102 mg.% at the time those statements are made. Thus, it is not possible, on the basis of our data, to completely rule out the possibility that after-effects of vestibular disturbances at least contributed to the production of decrements in performance under the alcohol condition.

V. Summary and Conclusions.

The performance of nine subjects was measured beginning approximately two hours after they had ingested 2.5 ml. of an alcoholic beverage per kilogram of body weight. Before being tested the subjects underwent several sessions on a rotating chair, but all reported that they had recovered from any effects of that experience prior to the beginning of testing. The performance tasks used involved monitoring (simple reaction time, choice reaction time, and meter monitoring), two-dimensional compensatory tracking and mental arithmetic. Three workloads were presented by varying the combinations of tasks the subject had to perform concurrently. These were: (A) monitoring plus tracking, (B) monitoring plus arithmetic, and (C) monitoring plus tracking plus arithmetic.

Significant workload effects were found for three of the four measures of tracking performance, for simple reaction time, and for movement time in the choice reaction time task.

Significant alcohol effects were found for reaction time in choice reactions, detection time for meter signals, and for three of the four measures of tracking. Mental arithmetic scores were not affected. There was a significant interaction between workload and alcohol with one tracking measure—RMS error in the vertical dimension. Nonsignificant interactions ($P<.10$) were found between alcohol and workload for absolute error in both dimensions for tracking performance and for reaction time and movement time in the choice reaction time task.

The conclusions to be drawn from this study support the previously reported findings with respect to the effects of alcohol on performance, a possible exception being the absence of a significant effect on mental arithmetic.

An important methodological conclusion to be drawn is that the time-shared performance of tasks involving the exercise of different psychological functions is a highly desirable condition to be used in conducting research on the effects of adverse factors on human performance. We also conclude that the sensitivity of these tasks to the effects of variables such as high blood alcohol levels is at least tentatively established. Modifications to decrease the variability of the simple reaction time measure and to increase the difficulty of the arithmetic task would seem to be in order.

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