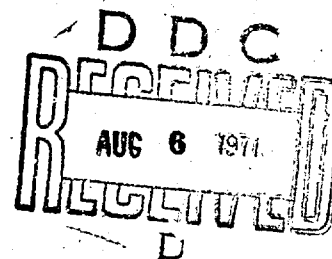


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Performance Enhancement under
Task Induced Stress

Paul M. Hurst

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Final Report

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13. ABSTRACT This final report summarizes published and unpublished research on a project investigating potentials for acute drug enhancement of performance under stress. Stressors include various task dimensions such as input pacing, memory storage requirements and competitive associations. Potentially deleterious influences from drugs, which could act to nullify enhancement gains, were also investigated. These include judgment impairment and rebound as aftermath of medication. Concurrent observations are reported for moderating influences such as individual differences, incentive motivation, fatigue, suggestion effects, stage of practice, task complexity, and association and usage frequencies of learned materials. Results suggest certain crucial task dimensions for performance enhancement or impairment by stimulant drugs. Task dimensions are also identified that moderate the impairment effects of commonly used depressant drugs such as alcohol, chlor-diazepoxide and the barbiturates.			

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Learning						
Delayed Recall						
Drug Rebound						
Paried Associates						
Driver Impairment						
Redundancy						
Overload						

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I. Publications Supported in Whole or Part by this Project

Technical Reports

- Hurst, P.M. & Weidner, M.F. Drug effects upon performance under task-induced stress. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-1.
- Hurst, P.M. A viewpoint on drug enhancement. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-2.
- Hurst, P.M. & Weidner, M.F. Drug effects upon cognitive performance under stress. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-3.
- Hurst, P.M., Perchonok, K. & Bagley, S.K. Drug effects upon performance as a function of data input rate. Division of Psychobiology, Institute For Research, 1967. Report ONR-H-67-1.
- Hurst, P.M., Radlow, R. & Bagley, S.K. Drug effects upon data processing as functions of storage and retrieval parameters. Division of Psychobiology, Institute For Research, 1968. Report H-67-2.
- Hurst, P.M., Radlow, R. & Bagley, S.K. The effects of *d*-amphetamine upon acquisition, persistence and recall. Division of Psychobiology, Institute For Research, 1968. Report ONR-H-68-1.
- Hurst, P.M., Chubb, N.C. & Bagley, S.K. Rebound from *d*-amphetamine. Division of Psychobiology, Institute For Research, 1969. Report ONR-H-69-1.
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- Hurst, P.M., Radlow, R. & Bagley, S.K. The effects of *d*-amphetamine and chlordiazepoxide on strength and estimated strength. Ergonomics, 1963, 11(1), 47-52.
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- *Hurst, P.M. & McKendry, J.M. Effects of redundancy on performance under overload stress. Percept. & Motor Skills, in press.

Book Chapter

- Hurst, P.M. Judgment distortion by amphetamines: some moderating influences. In Evans, W.O. & Kline, N.S. (eds.), Psychopharmacology of the Normal human. Springfield, Ill.: Charles C. Thomas Co., 1969, pp. 189-199.

Submitted for Publication

- McKendry, J.M. & Hurst, P.M. Adaptation to speed stress in an immediate memory task
- Hurst, P.M. Relative hazard at low blood alcohol: a statistical riddle
- *Hurst, P.M., Chubb, N.C. & Bagley, S.K. Rebound from α -amphetamine

In Preparation

- Hurst, P.M. & Bagley, S.K. Effects of alcohol and methylphenidate on complex judgments

*Revision of earlier technical report

II. Summary of Accomplishments on this Project

This section summarizes technical findings, theoretical developments, methodological innovations, and implications for utilization. It is intended to guide the reader to topics of interest that he may wish to pursue in Section III, and also for the busy administrator who needs a brief overview of the seven-year effort.

A. Major Findings from this Research

1. It was demonstrated that performance enhancement from *d*-amphetamine in a learning situation derives, at least in part, from enhancement of learning process. (Previous demonstrations had left some doubt of this in that the effect of the drug during tests given to demonstrate learning accomplishment had not been separated from the effects on original learning acquisition.)
2. It generally confirmed the previously reported wide range of performance enhancement by amphetamines at tasks of varying complexities and stages of learning, establishing a new anchor point at the simple end (grip strength).
3. It demonstrated that learning under these drugs is not state specific: It appears to transfer equally to a subsequent drugged or non-drugged state.
4. The research explored several possible sources of adverse effect from such medications. The much-feared impairment of "judgment" was found to occur, but only in certain situations. Amphetamines appear to induce greater self-confidence when ego involvement is high, but the effect is small and may serve only to raise underconfidence to a realistic level. The possibility of day-after "rebound" was also explored. It was found that it is possible to administer *single acute dosages* in amounts sufficient for temporary enhance-

ment in at least some tasks without a measurable rebound below the pre-drug baseline. In general, enhancement influences were stable over a wide range of task parameters. The only significant instance of reversal (impairment) occurred in a data processing task at an extremely high input rate. This was not a function of difficulty *per se*, and was tentatively attributed to an effect on filtering strategies.

It was also found that the enhancing influence of some stimulants may be reduced when a task has been very highly practiced. Conversely, the detrimental effect of a depressant (secobarbital) appears to be reduced by increased practice even when such practice takes place without the drug.

5. The possibility was explored that such drugs consistently enhance performance in some persons but have at best positive, or possibly negative, effect on others. This question has obvious practical as well as theoretical implications. It was found (by a test-retest design) that there is some personal consistency in this respect, but it was not possible to predict such individual differences from any of three comprehensive personality inventories. At present, the best predictor of the drug's effect seems to be a pretest with the drug on the particular individual.

6. Implications were explored for increased enhancement possibilities. It was found that the facilitative effects of stimulants do *not* depend on the prior existence of fatigue, boredom, or low motivation: They can still occur even when task conditions lead to a motivation that is "stressfully" high, as suggested by self-ratings on the Nowlis "anxiety" scale. In fact there was some evidence that the drug-enhancement influence may be greater under such circumstances, i.e., incentive payments or initial exposure to a highly demanding task. It was previously feared that stimulants, while useful to fatigued personnel, would have a reversed effect under conditions of high arousal. This now appears to be considerably less likely.

B. Theoretical Significance

Several of the findings discussed above have rather broad theoretical ramifications. Among these is the demonstration of true learning effects, and the development of a measurement paradigm for such when drug treatment is the independent variable. This research generally disconfirms the notion that drugs interact with motivational levels in a simplistic manner, as via the Yerkes-Dodson principle. There is, instead, increased evidence for a complex performance role on the part of mood-related, volitional influences. At least one negative demonstration has been made with respect to the "state dependency" hypothesis, as it concerns drug effects on human learning. Finally, there is the negative evidence: the failure to predict individual differences in drug effects on the basis of personality inventories, even though the former are of a potentially-predictable consistency. This suggests that such popular instruments are missing some aspects of trait organization that may be crucial at a fundamental level of behavioral chemistry.

C. Methodological Developments

Several procedural innovations were employed in connection with the findings discussed above. Among these is the delayed-recall paradigm for learning effects, and a design for separating true drug effects from "placebo" (suggestion) influences. The latter includes the drug-disguised condition previously employed by others but includes a complete factorial arrangement for resolution of "placebo" influence, "true" drug effect, and their interaction. A computerized analytical scheme has been developed for least-squares parametric estimates in sequentially balanced designs where imbalances, due to subject dropouts, occur. This is based on well-known mathematical principles but is superior to any approach currently available in "cookbook" form.

The most significant methodological development (not discussed above) occurred from this project in conjunction with another program of drug

experiments. This was the invention of the "modified group mean" (MGM) technique of generating a correlation matrix for factor analysis. This scheme allows the resolution of "drug x response" factors as distinguished from the customary "subject x response" factors. Like Cattell's *P*-technique, it focuses on the dimensions of state variation as opposed to the "trait" dimensions of the orthodox *R*-technique. However, it incorporates the stability of group means and largely restricts the variations being analyzed to those produced by drugs. Thus, data from several experiments having a common set of response measures can be used to resolve a set of "drug" dimensions: a response space within which any drug treatment can be expressed as a vector determined by its factor-score projections. This approach has been used to show that an amphetamine (either *dex* or racemic) has three separate, mood-related components. These are distinguished from one another by differential latency peaks and differential dosage/response functions.

D. Utilization of Findings

The question of utilization is a rather sensitive issue due to the drug-abuse notoriety of some of these compounds (the amphetamine group). However, such concern may be excessive. They are routinely prescribed for diet, and there would seem to be considerably less risk (and more of a warrant) for their occasional acute, controlled use in urgent military situations. Apparently, they are made available to astronauts, on the presumption that such employment is justified when it is vital to bring a man up to his full potential in a fatiguing or otherwise stressful situation. Such practices may be warranted, particularly in view of the demonstration that no measurable "rebound" occurs from single acute doses administered under medical supervision, even though these same doses have been shown to enhance performances on a variety of cognitive and perceptual-motor dimensions. For the navy's mission, the type and degree of

enhancement thus far demonstrated must be evaluated by the cognizant medical authorities in the light of anticipated task demands from various operations. In these is need for more research on moderator influences to furnish increasingly precise guidelines to such decision makers.

III. Review of the Research Effort

In this section we shall attempt to convey our general purpose in undertaking this program, and to explain the strategic sequences which arose during the course of the investigations. This will be done in connection with the summarized findings of each study in turn. With published studies we shall reproduce the original abstracts or summaries with references to guide the reader who wishes to pursue matters further.

To appreciate the goals of this project, one needs as a point of departure the state of the art at its inception in 1964. It has been demonstrated that a wide range of human mental and physical performances could be enhanced by drugs of the "stimulant" type (Weiss and Laties, 1962; Laties and Weiss, 1966). There have also been numerous separate reports of enhancement by various "depressant" drugs (Hurst, 1966), but the latter are trickier due to the strong likelihood of impairment instead of enhancement depending on sensitive considerations of dosage, latency, task variables, personality, and their many interactions. The stimulant group (notably amphetamines) seemed therefore the more attractive choice for a starting point. However, despite the numerous positive reports, there were also many of "no effect" and a few of actual impairment. We therefore set our task to try to discover the crucial parameters that thus differentiate the outcome. So as to vary only a few things at a time, controlling other influences, we conducted many of our experiments within a common task framework, the paced sequential memory task (PSMT). From time to time, specific questions or problems arose that initiated excursions into other task frameworks, conceptual modelling, or methodological researches.

A. Literature Review

Our first effort was to review the published literature for verifiable instances of drug enhancement, and to draw there from some inferences as to what drug enhancement is all about: what behavioral mechanisms may be involved, what task parameters embody them, what drugs affect these mechanisms and how such effects may be manifested in performance indices that are also influenced by other properties of any particular compound. We were impressed by the complexity of the problem, being convinced that most psychoactive drugs do more than one thing at a time and that adequate understanding therefore requires a large number of observation points. The following modified abstract describes this initial orienting effort:

Hurst, P. M. A viewpoint on drug enhancement. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-2.

Abstract: Pertinent experimental literature is reviewed concerning drug enhancement of cognitive performance. Results are synthesized into a viewpoint concerning psychological mechanisms by which performance can be enhanced, with emphasis upon stressful situations. Criteria are advanced for operational distinction of tasks and/or situations where enhancement effects may be predicted for particular classes of drugs. Preliminary specifications are devised for experimental verification of parts of the theoretical framework. (67 refs.)

B. The Paced Sequential Memory Task

The suggestion of an "anti-stress" component in stimulants of the amphetamine group inspired the first series of experiments with the PSMT. Most descriptions of such compounds concern dimensions related to their analeptic properties: "CNS stimulation," "arousal," "energizing properties," etc. Hence, one would not expect them to benefit performance in "stressful" situations, e.g., those in which subjects may be hampered by disorganizing emotional influences. A "stimulant" might be expected to hurt such performances rather than help them. Consequently, efforts to improve performance in such situations had customarily employed "depressant" drugs such as the opiates, barbiturates, or various ataractics, in the hope that emotional normalization would offset any direct cognitive impairment produced by such agents.

Mood measures, however, suggest that "stimulants" of the amphetamine group do more than is simply predictable from their analeptic properties. Increases in self-reported "boldness," "confidence," etc. and in risk-taking (Hurst, 1962) suggest the presence of a component that might have anti-stress effects. If it exists, this component could render such agents preferable to the depressants for "stress" situations since the former do not usually impair cognition in unstressed subjects: if anything, they usually tend to improve it.

Consequently, we set out to compare two stimulants with a minor tranquilizer and a no-drug baseline condition. For the task framework, we chose the paced sequential memory task (PSMT) devised by Lloyd, Reid and Feallock (1960). This task was employed in five related studies with *d*-amphetamine and various comparison drugs and will be briefly described.

The stimulus materials are presented orally by tape recordings and the responses are made with paper and pencil. The materials to be recalled, and their recall points, are intermixed. A word sequence consists of "member" words (e.g., pine, tin, polo) with "Class" words (e.g., tree, metal, sport) interspersed. When a class word is presented, the subject must recall the most recently presented item that belongs to that class (e.g., for "tree" recall "pine," etc.). The average storage load ($\overline{SL}$) can be systematically manipulated, and has been found to be a good predictor of performance over a range of task variations.

Since this task requires concurrent, mutually-interfering operations of registry, storage and retrieval, it was presumed to have a certain intrinsic stressfulness. This was subsequently confirmed according to mood self ratings, which showed a significant peak in the "anxiety" cluster correlated with test onset. In the first two experiments, stress was further manipulated via monetary performance incentives.

Hurst, P. M. & Weidner, M. F. Drug effects upon performance under task-induced stress. Division of Psychobiology, Institute For Research, 1966. Report ONR-66-1.

Summary

An experiment was performed to test the interaction between drug/placebo effects and incentive conditions in a "task-induced stress" framework. Its purpose was to test hypotheses concerning the relative roles of "psychoanaleptic" and "anti-stress" components in the drugs involved.

Sixty-three student volunteers were administered either *d*-amphetamine sulfate (10 mg), methylphenidate HCl (10 mg), chlordiazepoxide HCl (10 mg), or no drug. Half of each group received a capsule (placebo effect) and

half did not. In all cases, the drug was disguised in decaffeinated coffee given under the cover of a "taste perception test."

Self-ratings of mood were obtained with the Nowlis Adjective Check List. Performance scores were obtained from two tests with a forced-paced sequential memory task (PSMT). During the second test, motivation or "stress" was manipulated by requiring half of each drug/placebo group to work for a fixed ("low stress") payoff and half for an incentive payoff based upon performance ("high stress").

Significant mood effects were generally limited to changes in "fatigue" and "vigor," attributable chiefly to the energizing effect of *d*-amphetamine. In the PSMT, superior performance was obtained from *d*-amphetamine groups relative to the other drug and no drug groups. This superiority was significant at $p < .025$ during the first test, but declined progressively, and failed to reach statistical significance during most of the second test. The superiority of *d*-amphetamine over methylphenidate or no drug was limited almost entirely to the "high stress" condition. Essentially the same results were obtained regardless of whether subjects knew they had taken a drug.

Since the superiority of *d*-amphetamine was greater (1) under high stress and (2) during the earlier stages of testing, the results lent some support to the postulate of an "anti-stress" component for this drug. They tended to contradict the viewpoint that cognitive performance enhancement by amphetamines is dependent upon the prior existence of fatigue or boredom.

The first experiment had produced results suggestive of an anti-stress effect from *d*-amphetamine but part of the evidence was based on

trends that were short of statistical significance. It was desirable to replicate part of this study, using an increased number of subjects. However, we decided to discard the drug conditions showing little promise and to add some combination drugs that might heighten the effects observed with *d*-amphetamine alone:

Hurst, P. M. and Weidner, H. F. Drug effects upon cognitive performance under stress. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-3.

Summary

Experiment 2

Experiment 1 had shown some significant improvements of *d*-amphetamine over no-drug groups at the PSMT, with some indications that an anti-stress component was instrumental. Experiment 2 therefore included the previous dosage (10 mg) of *d*-amphetamine, taken either alone, combined with 50 mg sodium secobarbital, or combined with 10 mg chlordiazepoxide HCl. The additives were predicted to yield increased stress-mitigation. These medications were compared with "no drug."

A total of 136 paid student volunteers were randomly assigned to the four drug groups. Half of each drug group received a placebo capsule before testing, and half did not. The active drugs were dissolved in decaffeinated coffee administered in the guise of a taste perception experiment to increase the procedure's plausibility. The medications were ingested 65 minutes before the start of the 50-minute test session with the PSMT.

Level of stress was manipulated by randomly assigning half of each drug x placebo group to a fixed payoff condition, and half to "incentive

payoff" where the subjects' remuneration for the experiment was strongly dependent upon his performance in the PSMT. Thus, a factorial arrangement was achieved for drug x placebo x incentive conditions, similar to that employed in Experiment 1.

No significant treatment effects were obtained with the PSMT. Although all three drug treatments produced higher means than "no drug," the differences were smaller than previously obtained. Performance self appraisals were generally biased downward, although this bias was significantly ($p < .05$) reduced by the placebo effect. There was no significant drug or incentive effect upon this bias, although *d*-amphetamine showed a tendency to produce less favorable self-estimates of performance than any of the other drug/no-drug conditions, particularly when the placebo effect was also present. This finding is contrasted with that of Smith and Beecher (1964).

Contrary to some published results, no significant treatment effects were obtained regarding bias in estimated time duration.

A number of significant treatment effects and interactions were observed with the various mood factors measured by the Nowlis MACL, with the drug combinations producing effects which were generally stronger, and sometimes opposite from, the effect of *d*-amphetamine taken alone. The *d*-amphetamine + chlordiazepoxide combination yielded a mood profile that differed strikingly from that of the *d*-amphetamine + secobarbital combination.

The next experiment had the following goals:

1. To confirm or deny, with a more powerful experimental design, the previous trends suggesting that *d*-amphetamine enhances non-fatigued performance in the PSMT.

2. To explore dosage variations in this drug, including a higher upper limit.
3. To test the interaction of drug effects with input pacing.
4. To compare, for the various medications, the PSMT results with those on a supplementary non-paced task.
5. To contrast the *d*-amphetamine effects on both these tasks with those of secobarbital, a "depressant" predicted to have anti-stress properties but which also may ~~effect~~ direct cognitive impairments.

This experiment is also contained in the reference,

Hurst, P. M. and Weidner, M. F. Drug effects upon cognitive performance under stress. Division of Psychobiology, Institute For Research, 1966. Report ONR-H-66-3.

Summary

Experiment 3

Forty-eight paid student volunteers were randomly assigned to experimental sequences in a Latin square balanced for subject, periods, and residual effects. Five medications were administered on five evening sessions spaced by one-week intervals: (1) no drug, (2) sodium secobarbital, 100 mg, (3) *d*-amphetamine sulfate, 10 mg, (4) *d*-amphetamine sulfate, 15 mg, and (5) placebo. The last four medications were given in matched capsules. In each session, both the 42-minute PSMT and the 60-minute arithmetic task were performed under strong monetary incentives. A 30-minute interval between these tasks was occupied by the Nowlis Mood Adjective Check List (MACL), a time estimation task, and a 10-minute break. The entire procedure was designed to yield high task-induced

"stress" and minimal boredom. Input pacing for the PSMT was varied in counterbalanced order within each test session. Measures of mood and performance level were obtained at regular intervals throughout. Self-appraisals of performance were obtained, and compared with actual performances to test for bias. Time judgments were also obtained. At the end of each session, subjects were required to indicate how their medications had affected them, according to the categories "stimulant," "depressant," "tranquilizer," and "no effect."

Significant ($p < .01$) enhancement of PSMT performance was obtained with 15 mg *d*-amphetamine at both input speeds. The 10 mg dosage of this drug yielded a non-significant positive trend, comparable to the averaged results from the previous experiments. Significant ($p < .001$, $p < .01$) enhancement of arithmetic performance was obtained for the 15 mg and the 10 mg dosages, respectively. Secobarbital significantly depressed PSMT performance, and depressed arithmetic accuracy but not total correct. Its depressant effects diminished with repeated exposures to the tasks.

No significant drug effects were obtained for time estimation bias or performance self-appraisal bias. Both dosages of *d*-amphetamine reliably increased MACL ratings on the "elation" factor and decreased ratings on the "fatigue" factor.

The coefficient of concordance between actual drug categories and self-rated effects was .24 (non-significant).

The absence of significant drug-induced biases in time estimation was at variance with published data concerning amphetamines and secobarbital. This discrepancy did not yield to ready explanation. The absence

of significant effects upon performance judgments such as shown by Smith and Beecher (1964) was also enigmatic. It was suggested that certain task demand parameters may moderate any drug-induced tendencies toward optimistic or pessimistic self-appraisal, an hypothesis subsequently to be tested (Hurst, 1969).

The third experiment had confirmed that *d*-amphetamine does, indeed, exert a dose-related enhancement influence on performance in the PSMT by subjects who are not sleep-deprived and are working under strong monetary incentives. However, the question of stress mitigation was still in doubt, particularly since the drug also improved performance in a simple arithmetic test that was presumably far less "stressful." It was possible, of course, that a different component was involved in the latter; we may simply have been observing in the latter the well documented anti-boredom component of amphetamines (Hurst, Kadlow and Weidner, 1968). To elucidate the mechanism of PSMT enhancement, it was desirable to incorporate further variations in the conditions of the PSMT itself. Consequently, a fourth experiment was designed which included "input rate" at a higher level, with greater temporal separation between rate conditions to allow for the buildup of emotional influences. For comparison we also administered chlordiazepoxide HCl in a higher dosage, believing that 10 mg dosage employed in Experiment 1 was probably insufficient:

Hurst, P. M., Perchonok, K. and Bagley, S. K. Drug effects upon performance as a function of data input rate. Division of Psychobiology, Institute For Research, 1967. Report H-67-1.

Summary

Four drug treatments were administered to each of 58 college student

volunteers who served as their own controls in a replicated Latin square design. The treatments were *d*-amphetamine sulfate (11-17 mg), chlordiazepoxide HCl (25 mg), placebo, and no drug.

Performance was tested at a 30-minute paced sequential memory task given at 70 minutes after ingestion and again at 130 minutes after ingestion. Input speed was set at two levels, 30/minute and 60/minute, counterbalanced with respect to latency. The severe limitations on response time imposed by the 60/minute rate necessitated a change in the procedure for recording answers. Previously, the subject had been required to write the first three letters of the correct word. Now, he was given (under both rate conditions) an alphabet block for each answer, with instructions to draw a line through the beginning letter of the answer word.

Chlordiazepoxide significantly depressed performance at the 60/minute level and non-significantly at the 30/minute level. *D*-amphetamine significantly depressed performance at the 60/minute speed, and nonsignificantly enhanced it at the 30/minute speed. No differentiation was obtained with respect to the drug latency variable.

These results are opposite to what was predicted from the hypothesis that *d*-amphetamine enhancement of PSMT performance, as observed previously, reflected an anti-stress component. In view of the earlier, positive outcomes regarding latency and incentive phenomena, we were not yet ready to abandon the anti-stress interpretation. The most obvious alternative, that only boredom-mitigation was involved, had been largely discredited by these earlier results. However, the anti-stress concept needed to be reexamined and the possibility of a third mechanism considered. At this

point, there appeared to be three possibilities:

Hypothesis 1: Enhancement is reversed because d-amphetamine intensifies the emotional response to "failure stress."

It is possible that, although the drug enhances performance in a demonstrably threatening task situation, this effect is reversed when task demands appear "impossible." Amphetamines seem to increase the utility of high achievement (Evans & Smith, 1964; Hurst, 1969). This may raise level of aspiration and thus activate the "need to avoid failure" when the subject realizes that he cannot achieve such a level.

Threat of failure can be removed by refusing to try.

Hypothesis 2: The method of recording answers may moderate the drug effects.

The letter-checking technique introduced to cope with the high input rates in Experiment 4 requires more searching but less motor activity than the letter-writing technique previously employed. Failure of enhancement with letter-checking could suggest that the enhancement previously observed, in experiments using the letter-writing technique, resulted simply from an increase in the speed with which subjects could write down letters (cf. Laties & Weiss, 1966).

Hypothesis 3: D-amphetamine influences data-processing strategies in a manner which leads to impairment at very high input rates.

High input rate imposes filtering demands which increase progressively as the rate goes up. Again assuming that the drug increases utility of achievement, this effect may combine with increased self-confidence to prevent a realistic degree of filtering at very high input rates.

These hypotheses are not mutually exclusive nor are they exhaustive, but they seemed to represent the more plausible possibilities. Hypothesis

2 could be tested very easily by simply alternating methods of recording answers, giving tests of each type in counterbalanced order within each session. This, of course, demanded use of input rates below the 60/minute range. Discrimination between Hypotheses 1 and 2 could be aided by varying difficulty level over a wide range without changing input rate -- i.e., by use of a factorial arrangement of list length and average storage load, using a wide range of each. If difficulty *per se* is the crucial moderator (as implied by H1), then reversal of enhancement should not be specific to very high input rates but should occur with any combination of task parameters that results in similar difficulty, as revealed by percentage of correct responses. If coding strategies are affected in a manner whose detrimental influence is specific to high input rates, then enhancement reversal would not be expected under similarly difficult ranges of list length and storage load.

It was also desirable to include another test for the role of emotional influences. This could be provided by comparing amphetamine and placebo effects with those of amobarbital and with a *d*-amphetamine-amobarbital combination. It was anticipated that the latter would produce a stronger affective response than *d*-amphetamine alone. However, the barbiturate component might also produce a direct cognitive impairment. Interpretation of the combination drug's effect would be facilitated in this respect by comparing it with the effect of amobarbital given separately:

Hurst, P. M., Radlow, R. and Bagley, S. K. Drug effects upon data processing as functions of storage and retrieval parameters. Division of Psychobiology, Institute For Research, 1968. Report H-67-2.

Summary

In this study, the drug conditions were (1) *d*-amphetamine sulfate (15 mg/77 kg) (2) sodium amobarbital (96 mg/77 kg), (3) a combination of both drugs in the same dosages, and (4) placebo. Task variations were imposed upon storage load, list length, and method of transcribing answers (varying motor requirements). Results were analyzed both with and without statistical corrections for guessing.

Results showed significant enhancement by *d*-amphetamine in total performance across conditions, with no indications of dependency upon storage load, list length, or method of transcribing answers. The margin of superiority over placebo showed little variation across these conditions, nor was it appreciably changed by correction for guessing. Amobarbital given separately was closely comparable to placebo. When combined with *d*-amphetamine, it showed a non-significant weakening of the enhancement effect. Contrary to expectation, it also weakened the mood effects, thus precluding the anticipated test of affective components in the performance results.

These results indicated that amphetamine enhancement does not crucially depend upon task difficulty within the ranges employed, nor upon length of exposure to task or the motor requirements of answer-writing, nor does it depend upon the premium placed on willingness to guess. Reversal of *d*-amphetamine enhancement, obtained in the preceding study, was tentatively attributed to increases in requirements for input "filtering," i.e., the need to reject usable data when processing capacity is overtaxed: amphetamines make people reluctant to accept the need to "filter." This was the only hypothesis that was not overthrown by the data.

Due to our perceived inability to penetrate further into the "black box," i.e., to measure directly which inputs were filtered out and which were lost by default, this study concluded the PSMT work. The results of the entire series are summarized in the following reference, which also includes the detailed description of the final experiment:

Hurst, P. M., Radlow, R. and Bagley, S. K. Drug effects upon data processing as functions of storage and retrieval parameters. Ergonomics 1970, 13(4), 435-444.

C. Learning Enhancement

From the PSMT series and other published data, it has become established that acute doses of amphetamines can temporarily enhance a wide variety of performances. A question now arises as to what are the longer-term effects of such enhancement. Deferring till later the questions of physiological cost, abuse potential, etc., one may wish to consider whether the performance effect itself represents is strictly a temporary influence, associated with fatigue mitigation, "anti-stress" components, or whatever. Is there also the possibility that *learning* may be affected either favorably or adversely, so that the performance effects of acute medication may greatly outlast the duration of the pharmacological state thus imposed? Previous researches have left this question unanswered. There have, indeed, been a number of studies in which amphetamines were found to facilitate performance during various stages of learning. None of these, however, succeeded in isolating the effects of the (drug) agent present during learning from those of the agent present during the test of recall. The problem is a familiar one in tests of various motivational influences. To measure incentive effects on learning, one must compare

learning-incentive conditions on the basis of recall tested after the incentives have been "turned off."

Since drugs cannot be turned off as quickly as incentive schedules, the only crucial test of drug effects on learning is furnished by measuring delayed recall at some time after the drug has worn off. In addition, it was desirable to test for state-specific influences by crossing over the treatments employed during acquisition and delayed recall.

Paired-associates learning furnished the desired task framework. To enrich the findings, we manipulated usage frequencies, association values, and intralist competition. Published data (DiMascio, 1963; Weitzner, 1965) had shown that intralist competition is a moderator of certain drug influences during paired-associate learning, although they did not separate these influences on the separate functions of acquisition, persistence and recall. Also, there was no proof that the "competitive" influence was from competition *per se*. DiMascio did not include low-competition lists for comparison. Weitzner's high-competition lists were more difficult than his low-competition lists, so the crucial moderator may have been difficulty rather than competition *per se*. To remove ambiguity from our results, we varied usage frequency and association value within the low-competition series so that results could be contrasted either by difficulty level or by competition at constant difficulty:

Hurst, P. M., Radlow, R., Chubb, N. C. and Bagley, S. K. Effects of *d*-amphetamine on acquisition, persistence and recall. Amer. J. Psychol., 1969, 82(3), 307-319.

Summary

The experiment was designed to measure four component effects of

d-amphetamine in a paired-associate learning task. The drug was compared with placebo to reveal (1) effects upon acquisition of new material, (2) persistence of material so learned, (3) effects of drug present during test of delayed recall, and (4) interactions between drug present during learning and drug present during test of delayed recall. Paired associates of varying degrees of usage frequency, association value, and intralist competition were employed. Sixty-nine college men were tested in two sessions, for learning and delayed recall respectively. Presence of *d*-amphetamine (14 mg/kg) during learning resulted in significantly greater delayed recall of the low-competition lists and nonsignificantly greater delayed recall of high-competition lists. The same dosage given for the recall session had no significant effect upon delayed recall or relearning. The persistence effects attributable to drug presence during acquisition were not significantly influenced by whether or not the drug was also present during recall. In the "persistence" data, there was no suggestion of an interaction between drug effect and usage frequency. There was a trend toward interaction between drug and competition, in the direction reported by Weitzner as reflected by the significance of drug effect at low competition but not at high competition. This may, however, have been due to difficulty as opposed to competition *per se*, there being a significant interaction between drug and association value. However, this in turn may have been a ceiling-effect artifact due to the ease of the high-association lists. Consequently, one cannot conclude that the observed persistence effect was moderated either by difficulty or by competition *per se*.

D. Complex Data Processing

In a study whose results are still being analyzed, we undertook

to measure complex information-processing and decision-making influences in the framework of bidding problems from contract bridge. We wanted a task of such complexity so as to study the interactions of drug effects with such information-theoretic parameters as storage load, ambiguity, and response format (whether the adequate response must be searched for, from a stored repertoire, as opposed to selection among multiple-choice alternatives.) Because of the need for highly extensive pretraining in such a complex situation, it seemed undesirable to construct a new experimental task; rather, we sought a task for which reasonably proficient subjects already existed. In addition, we wanted to test the interaction between expertise and the drug influences. We had previously found that increased practice tended to reduce susceptibility to amphetamine enhancement or barbiturate impairment. There is also evidence that alcohol has less effect on highway crash probability in more experienced drivers, although the driving experience variable is contaminated by a number of other demographic attributes.

In this experiment, fifty student volunteers served as their own controls in a balanced Latin square design including (1) ethyl alcohol, 60 g/70 kg, (2) methylphenidate HCl, 12 g/70 kg, (3) methylphenidate HCl, 20g/70 kg, and (4) placebo. They were pre-tested without medication to measure initial proficiency and derive an experimentally-independent response distribution for the 160 problems subsequently employed. This was used to derive 'ambiguity' indices according to the information measure. During subsequent drug sessions, these same problems were used again (without feedback of results), each problem being given once in open response format and once in closed, multiple-choice format. The format variable

was counterbalanced with storage load (no. of preceding bids) and the competitive-non competitive bid variable, and all three of these variables were counterbalanced for drug latency.

Since analysis is still in progress, no results summary is available as yet.

This concludes the reporting of those experimental studies that were directly oriented toward pharmacological enhancement of performance under stress. The rest of our effort has been aimed at associated problems. This will be recounted in two categories, "Background Studies" and "Deleterious Influences."

E. Background Studies

In attempting to predict what effects particular drugs will have on particular performances, one is hampered by lack of understanding about (1) the basic behavioral dimensions of drugs, and (2) the dimensions of tasks that make them stressful, or otherwise amenable to pharmacological enhancement.

1. Mood Dimensions

In the drug-dimension category, we have been concerned with drug influences on affectively toned phenomena derived from self-reports: mood ACL clusters such as *fatigue*, *vigor*, *anxiety*, and *confidence*. These have constituted a major source of hypotheses about performance effects. As expressed in the *Viewpoint* paper, we do not think any "simple" drug is likely to enhance normal performance in the absence of prior degrading influences. If absorption in the bloodstream of a simple molecule could enhance total performance across all situations, it would probably be there already. What such a drug can do is help counteract various adaptation mechanisms that become maladaptive in the exigencies of a particular

situation. We have therefore been concerned with anti-boredom effects, anti-anxiety or "confidence" effects, etc. Accordingly, drug influences on mood descriptors have been a major source of hypotheses.

Although of great value in this respect, mood ACL categories are ambiguous in that they cannot be interpreted at face value. For example, amphetamines have been variously reported to increase self-reported "vigor," "relaxation," "anxiety" and "boldness," sometimes in the same subject population. Part of the confusion may stem from semantic vagaries and part from differential latency peaks of various mood dimensions. To clarify the semantics, factor analysis is applicable, as conducted on the mood ACL by Nowlis and Green (1957). However, "trait" factors derived from R-type analysis as in their work may not represent the primary dimensions of "state" change, especially when the latter represent effects produced by drugs. Consequently, a new analytical technique was developed and applied to mood ACL data obtained from six previous experiments in which a total of 502 subjects were measured under 58 combinations of drug x dosage x latency.

Hurst, P. M., Radlow, R. and Perchonok, K. Some dimensions of affective response to drugs. Psychol. Rep. (Monog. Suppl. 1 - v. 24), 1969, 24, 239-261.

Abstract: This study is an attempt to dimensionalize the affective responses of normal humans to some common psychoactive drugs. To this end, the methods of factor analysis were applied to a drug x mood correlation matrix. This technique differs radically from previous applications of factor analysis to mood effects, in that the latter char-

acteristically analyze a mood x subject matrix. Thus, instead of reflecting the organization of individual differences, the resulting factor structure represented a mood-dimension space in which drug effects were resolved as vectors. Amphetamines were found to produce strong effects along three mood dimensions, whose relative strengths depend upon dosage, latency, and a strong dosage x latency interaction. Susceptibility to independent manipulation by dosage-latency variations implies that the three dimensions constitute more than statistical abstractions and may represent isolable biochemical events.

A subsequent analysis on a new data base was performed to determine whether this MGM factor structure was stable in the face of (1) addition of further mood descriptors and (2) addition of different types of drugs. Preliminary results verified (1), but are inconclusive regarding (2). Although a three-dimensional structure was again obtained, the rotated factor loadings changed considerably. Further analyses are now underway to determine how much of the latter change is attributable to differences in scoring procedures.

2. Individual Differences

In the prediction of drug enhancement, it is obvious that group-mean analyses may be missing the major point and can even result in the cancellation of oppositely directed influences. Hence, we wished to employ a wide variety of personality "trait" measures in a preliminary screening effort to see if any of them would predict differences to mood

response to any given drug treatment. We also had another question. If such predictive power were lacking, could the failure of prediction be attributed to deficiencies in the predictors (trait indices), or were the differences to be predicted inherently unpredictable? If an individual response atypically to Drug X, does this aberration reflect a stable personal attribute or is it merely a transient occurrence? This seemingly obvious question has been seldom addressed, and the reason lies in popular models of experimental design. Obviously, the repeated-measurements model is not sufficient; each subject must not only receive each comparison treatment, but he must receive it at least twice on separate occasions. We therefore constructed a "double Latin square" in which each subject received each treatment twice, with order and residual effects counterbalanced. The treatments were *d*-amphetamine (15 mg/77 kg) amobarbital (96 mg/77 kg), a mixture of these two, or placebo. The first, self-contained half of this experiment constituted a two-person game study under separate sponsorship; the second was the *d*-amphetamine-amobarbital PSMT study reported above. Mood measures from both halves were employed to test (1) predictability from personality variables and (2) inherent predictability, as measured by test-retest correlations within treatment conditions.

We were totally unable to predict individual differences in mood response to these medications, even though we employed forty personality attributes derived from three widely used instruments (UPI, Barratt Personal Preference Scales, and Jackson PRF) in the attempt to predict any one of eleven mood dimensions from a modified form of the Nowlis Mood ACL at two different latencies, plus a measure of critical flicker fusion. As was to be expected with 960 correlation coefficients, a number

were "significant" at conventional levels (just about the number expected on a sampling basis). Cross validation of the significant relationships with data from a further experiment was a complete failure.

As indicated above, we were interested in comparing this predictive "power" with an estimate of the inherent predictability of the data. Results showed that mood response to a drug on one occasion is related to the response when the same drug is subsequently administered. Under *d*-amphetamine, the reliability of the response to be predicted ranged from zero to 0.70 over the eleven mood indices, with a median of 0.51. Under amobarbital the median reliability was 0.14; and under *d*-amphetamine plus amobarbital, it was 0.29; under placebo, it was 0.30. Thus, only *d*-amphetamine showed a consistency above or beyond the consistency of placebo response. This condition also produced the strongest mean effects on most of the mood measures.

Hence, it could be inferred that the mood response to *d*-amphetamine is potentially predictable, especially if one does not seek to remove from it the probable placebo component. Failure of standard personality inventories to achieve prediction is not readily explainable, but suggests that one might better look for predictive relationships in some other domain.

These results have not been published.

3. Speed Stress

These studies deal with the second phase of the "Background" problem, namely, the need to better understand task dimensions. Specifically, we desired to learn more about the dynamics of sequential memory tasks to elucidate the role of emotional influences ("panic")

that may normally degrade performance and hence render it susceptible to enhancement by anti-stress agents. Results from untreated subjects could advance this understanding. Such data were available from two earlier studies conducted by project personnel, but they had not originally been analyzed with such purposes in mind, nor had any of the results been published. Both had been conducted with the same basic task, which resembles the PSMT in demanding concurrent or intercurrent operations of perception, short term storage (recirculation), and retrieval. This task, however, required synthesis of two or more sequential elements to effect the correct response, which was the identification of a matrix of such elements. The elements themselves consisted of single squares, triangles, or circles presented one by one with a grid outline via slide projection. Two or three such elements provided enough information to uniquely identify the pattern as one of eight possibilities or as none of the above. These eight alternatives were continuously displayed, but the stimulus elements had to be stored; when the n th element of a sequence was presented, the $(n - 1)$ th element and prior ones could not longer be seen. Although no mood self-ratings were obtained, this task was adjudged to be stressful on the basis of subject comments. (One of them quit in the middle of a session although he had to walk two miles to get home.)

a. Information Transfer Functions and the Role of
Adaptation

As input rate is increased, one naturally expects a decline in percentage correct. The question, however, is whether this decline is steep enough to result in reduced information transfer rate, as reflected by the number of correct responses per unit time. Without

such an effect, one could not reasonably postulate the existence of disorganizing influences such as panic.

This speed effect was tested in the first experiment and strongly confirmed. Pattern size-complexity, the other variable, also had powerful performance effects but the performance plot for this variable was differently shaped. While steep throughout, the curve did not show the accelerated form found for input rate. The major effect of this variable was to change the threshold at which rate effects began to produce the accelerated decline in performance.

A second question to be addressed concerned the role of practice under the severe conditions associated with rapid information-transfer decline. One would expect fairly rapid adaptation to any emotional influence, although practice effects could also be attributable to development of better filtering strategies, etc. Results showed considerable improvement from practice when the conditions were near the threshold for the information transfer function, but relatively little improvement under still more severe conditions. Results were submitted for publication.

b. Redundancy and Transfer of Training

Hurst, P. M. and McKendry, J. M. Effects of redundancy on performance under overload stress. Percept. and Motor Skills, in press.

Summary

This experiment assessed the role of redundancy under the severe conditions associated with decline of information transfer. Stimulus sequences were constructed so that only two elements were sufficient

for an unique identification. In the zero redundancy conditions, only two elements were given per sequence. Under "medium" redundancy, three were given and "high" redundancy consisted of four. In either of the latter conditions, any two of the elements given were sufficient for unique identification. However, there was an added speed stress effect since the elements sequence, whether 2, 3, or 4, was presented during a constant time interval. This was done to provide a tougher test of redundancy, since a constant interval between elements would have resulted in greater inter-response times with the longer, redundant sequences and would thus have imposed a slower information-transfer rate.

Since the inter-response interval was constant, the information transfer rate was a linear function of the percentage of correct responses. Results were therefore analyzed in terms of the latter, which revealed a well-defined optimum at "medium" redundancy. Presence of an optimum suggests the operation of two or more mutually opposed influences having different slopes. Accordingly, the results were analyzed according to the assumption that a given element is either lost completely or is employed to effect a positive identification (or, when only one element remains, to make an efficient guess). This permitted separate calculation of the speed stress function and the opposed "insurance" function from the redundant elements. The former was found to be little affected by the change in element arrival rates from the zero to medium conditions, but to increase very steeply from medium to high.

A posttest involving crossed over conditions for groups trained at different redundancies showed similar main effects from redundancy levels

used in the posttest but failed to show any interaction between practice and posttest conditions: transfer of training was essentially uniform.

Taken together, the results of both experiments support the existence of some strongly disorganizing influence at high input rates: something that accelerates so fast in the critical region as to be almost qualitative. The second experiment reveals that this speed-stress influence is not imposed by limitations on the enter-response interval, being manifested from variations in element arrival rate at a constant response pacing. This narrows the range of possibilities. If no emotional influence is crucially involved, then the disorganizing influence might stem from limitations in the rate at which stimulus elements can be entered into temporary storage, which seems unlikely at the rates employed.

Another possibility is that the high-redundancy subjects continue (over thousands of practice trials) in trying to store more elements than they need, and hence exceed storage capacity. Such a persistently maladaptive strategy might suggest a role for disorganizing emotions.

F. Tests for Deleterious Influences

Although drugs enhance certain performances, the improvement may be outweighed by other effects of a deleterious nature. For the amphetamine group, two major possibilities have been frequently suggested. First, the drug may engender overconfidence sufficiently to have disastrous consequences. Secondly, the temporary enhancement effect may be followed by a rebound (in the particular functions thus enhanced) that drops performance below the pre-drug baseline. Chronic effects from repeated administration are apparently beyond question, but we are here concerned with single acute doses administered under supervision.

Even under this condition, does the immediate rise in performance incur a physiological debt that must be subsequently repaid?

1. Judgment Effects: Performance Self Appraisals

In connection with the PSMI series, it was pointed out that amphetamines do not induce bias in performance self appraisals. This seems inconsistent with the results reported by Smith and Beecher (1964), who found that racemic amphetamine (14 mg/70 kg) caused students to over-appraise their performances at calculus tests. Their result was confirmed by Hurst, Weidner and Radlow (1967) with a mathematical reasoning test, *d*-amphetamine (14 mg/70 kg) having a greater effect than the racemic compound in the same dosage. They also found that their subjects would wager real money according to these self appraisals.

Since task structure seemed to be the moderating influence, we decided to assess the effect on a grossly different test, that of simple grip strength:

Hurst, P. M., Radlow, R. and Bagley, S. K. The effects of *d*-amphetamine and chlordiazepoxide upon strength and estimated strength. Ergonomics, 1968, 11(1), 47-57.

Abstract: Four drug treatments were administered to each of 58 college student volunteers who served as their own controls in a Latin square design. The treatments were *d*-amphetamine sulfate (11-17 mg), chlordiazepoxide HCl (25 mg), placebo and no drug. Grip strength was measured on a Stoelting hand dynamometer 3 - 3 1/2 hours after ingestion. Prior to giving their maximum effort, subjects were required to estimate their strengths on the basis of perceived

effort required to reach an assigned submaximum value, determined as a percentage of masked pre-test scores. Objective strength was significantly high under *d*-amphetamine than under any other treatment condition. The treatments did not differ significantly with respect to estimated strength or estimate bias; indeed, there was a tendency for subjects under *d*-amphetamine to be more conservative.

These rather surprising results implied that there is something about mathematical reasoning tests that is not shared, in the college-student population, by either the PSMT or the grip test. The performance is obviously much more complex and a number of possibilities exist for the crucial dimension. This inspired a critical review of judgment effects and related phenomena which implicated ego involvement as the crucial moderator. This hypothesis was supported by a supplementary analysis of the results obtained in the mathematical reasoning test which showed that the more proficient subjects tended to show more bias in self-appraisals made under the drugs:

Hurst, P. M. Judgment distortion by amphetamines: some moderating influences. In Evans, W. O. and Kline, N. S. (eds.), Psychopharmacology of the Normal Human. Springfield, Ill.: Charles C. Thomas Co., 1969, pp. 189-199.

Summary

Judgmental and decision-making effects of amphetamines, drawn from the published literature, were examined for dimensionality. Effects were

analyzed in terms of a model for predicting choice behavior from subjectively expected utility. The issue addressed was whether the judgmental effects of amphetamines represent differential changes in outcome utilities, or changes in the subjective probabilities attached to different outcomes.

Results from three recent experiments by the author and his colleagues were applied to this issue. This evidence showed that neither of the decision-theoretic constructs is sufficient. Drug effects upon decision making in one uncertain-outcome situation were shown to involve significant changes in subjective probability. However, the effect is not stable when task conditions are changed. This suggests that the effect upon subjective probability is mediated through differential changes in outcome utilities.

Tentatively, it was concluded that amphetamines multiply differential outcome utilities by strengthening "need for achievement." Subjective probabilities of performance outcomes are affected only under conditions where these outcomes are relevant to the achievement motive.

2. Rebound

Although optimistic judgment effects were shown for amphetamines, they were mild and usually in the direction of greater accuracy. There remained the more serious possibility of adverse performance effects in the form of sub-baseline rebound following the initially facilitative enhancement influence. To test for this, we needed indices that were sensitive to amphetamines as revealed by initial enhancement, but that could be obtained quickly enough to permit repeated measures over the crucial time intervals. In addition to the

mood ACL, we chose the coding test that Smith *et al* (1963) found sensitive to amphetamine enhancement and the letter-checking task employed by Hurst, Radlow and Weidner (1968) with similar results. We added the measure of verbal production (word count from an impromptu "editorial") that had been found to be highly sensitive to *d*-amphetamine (Hurst, Radlow, Chubb and Bagley, 1969). Thus, the "rebound" to be assessed could be defined as a reversal of the earlier enhancement:

Hurst, P. M., Chubb, N. C. and Bagley, S. K. Rebound from *d*-amphetamine.

Division of Psychobiology, Institute For Research, 1969. Report
ONR-H-69-1.

Abstract: Forty-three university students, recruited as paid volunteers, served as their own placebo controls in an experimental test of immediate and delayed effects of *d*-amphetamine sulfate in separate doses of 10 mg and 15 mg. The question to be answered was whether short-term performance enhancement, obtainable in some tasks with amphetamines, is paid for by a subsequent impairment of performance below the pre-drug baseline: a rebound effect that may occur independently of intervening experience, sleep deprivation, etc.

Immediate and delayed ("rebound") effects were assessed with three tasks in addition to a mood self-check list. The tasks included letter-checking, a coding test, and a test of verbal production (number of words written impromptu on an assigned topic during 25 minutes). Neither the coding nor the letter-checking provided a check of the hypothesis. Coding showed no significant effects during

either the immediate tests (1.5 to 3 hrs. after ingestion) nor during the delayed tests (19.5 - 21 hrs. and 24 - 25.5 hrs. after ingestion). Letter-checking showed a significant enhancement in the test of immediate effects, but the enhancement margin was so small that the subsequent absence of "rebound" was inconclusive. Both verbal production and mood effects, however, showed strongly positive effects on the immediate tests, with no indication of subsequent "rebound." This finding suggests that acute medication can yield temporary enhancement without subsequent impairment beyond a return to the pre-drug baseline. This conclusion is, of course, restricted to the use of single dosages in situations where intervening activity and sleep deprivation are controlled.

A revised version of this report has been submitted for journal publication.

3. Effects of Alcohol at Low Blood Concentrations

The effects of beverage alcohol on automobile crash incidence are, in a general way, well known. Only in recent years, however, has it been possible to calculate exposure-adjusted estimates of relative hazard. This required "controlled" studies in the sense that a field study can be controlled by comparing incidences of particular blood alcohol concentration (BAC) in crash victims with corresponding incidences among randomly-sampled drivers who happened to be traversing the crash area at similar times of the day or week. A Bayesian procedure was developed for converting these relative incidences,

which directly yield "probability of BAC_j given a crash," into their inverses (probability of a crash given BAC_j). This procedure was applied by Hurst (1970) to four published data sources.

Of particular interest to this project is the suggestion of performance enhancement at low BAC implicit in the famous Grand Rapids study (Borkenstein *et al*, 1964). The reduction in relative crash incidence in the range of 0.01% - 0.04% BAC is obvious on cursory inspection of the case/control ratios at these levels, compared to that observed at zero BAC. This suggests some sort of enhancement influence. If the phenomenon is acceptable at face value, it would inspire laboratory efforts to manipulate the effect and learn how it is mediated. However, the Grand Rapids data also include case-control/BAC tallies that are further broken down by self-reported habitual drinking frequencies. When relative hazard functions were computed separately for these subgroups, a different implication emerged:

Hurst, P. M. Relative hazard at low blood alcohol: a statistical riddle.

Submitted for publication.

Summary

A Bayesian analysis of relative hazard as a function of blood alcohol concentration (BAC) was applied to crash/control tallies from the Grand Rapids study subcategorized as to self-reported drinking frequency. Results suggest that an individual driver's crash hazard is a monotonically increasing function of BAC, rather than being reduced within the 0.01% to 0.04% range as has been widely quoted. More strongly, the data imply that relative hazard estimates derived from a composite driver

population give a strongly distorted impression of alcohol's dose/response function for crash probability. Relative crash incidence at varying BAC is a valid basis for estimating loss reduction from an enforced BAC limit but has very limited bearing on the expected results of manipulating BAC within an individual or demographic subgroup. Applicability of these findings is limited by the apparent need to rely on self-reports, but there may exist a warrant when drinking experience is presumed to be low as with under-age drivers.

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