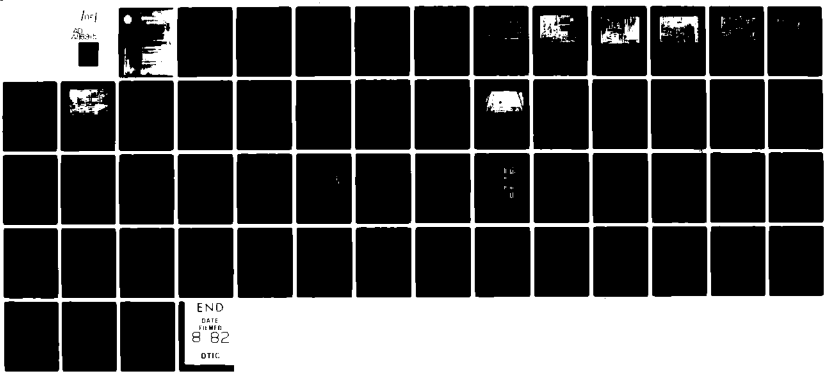
AD-A116 915 JOHNS HOPKINS UNIV BALTIMORE MD DEPT OF PSYCHIATRY F/G 5/9
EXPERIMENTAL ANALYSIS OF TEAM PERFORMANCE: METHODOLOGICAL DEVEL--ETC(U)
JUL 82 H H EMURIAN, J V BRADY, R L RAY N00014-80-C-0467
UNCLASSIFIED TR-ONR-6 NL



SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-ONR-6	2. GOVT ACCESSION NO. AD-A116 915	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Experimental analysis of team performance effectiveness: Methodological developments and research results		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Henry H. Emurian, Joseph V. Brady, R. L. Ray, James L. Meyerhoff, and Edward H. Mougey		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0467
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychiatry The Johns Hopkins University School of Medicine Baltimore, MD		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 170-910
11. CONTROLLING OFFICE NAME AND ADDRESS Organizational Effectiveness Research Programs Office of Naval Research (Code 452) Arlington, VA 22217		12. REPORT DATE 6 July 1982
		13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Programmed environment, behavioral program, team turnover, team task

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a description of a programmed environment research laboratory that was designed and constructed to support functional analyses of individual and team performance effectiveness viewed conceptually within the context of a small-scale microsociety. The technical and organizational merits of a behavioral program, which structures team members' use of resources in a disciplined yet meaningful way, are suggested as a promising solution to the problem of motivating and monitoring individual and team performances. Summarized are previous research emphases and findings as are more recent analyses of effects of replacing an established team participant with a novitiate team member. Finally, the results of such a "replacement" analysis, which was undertaken with a Team Multiple Task Performance Battery (TMTPB), are presented to demonstrate the dynamic interplay between individual and team performance effectiveness.

Where the successful accomplishment of an organization's mission requires the coordinated contributions of two or more individuals collectively identified with the achievement of a common objective, the conditions for characterizing a team are operationally defined. For the most part, observations of team performance under operational, training, and simulation conditions that emphasize brief or extended exposure of team members to constant scenario environments have been limited by the constraints imposed on experimental interventions. Indeed, a review of the extensive literature in the area suggests that research on team performance effectiveness would be advantaged by the development and application of an effective methodology for extended-duration analyses of both the functional and topographic aspects of such situations under conditions that provide for operational task assessment and evaluation within the context of a comprehensive living and work setting (1,2).

Accordingly, in response to the growing recognition of the importance of developing technological guidelines related to (1) the impact of the type of mission, (2) the characteristics of team participants, and (3) the skill level of a novitiate participant as they affect a team's ability to accomplish mission objectives, a research project was undertaken to investigate performance effectiveness within the context of a laboratory environment in which both interpersonal and work behaviors can be continuously monitored and evaluated over extended time periods (e.g., days). Rather than simulating a targeted operational environment exhibiting a high degree of physical realism at the expense of flexibility of researchable problems to be addressed within such a setting, the present laboratory facility was designed to address a broad range of performance problems from the perspective of a functional analysis of performance effectiveness. This analysis emphasizes the assessment of relationships between antecedent conditions (e.g., membership turnover, training methods, etc.) and performance effectiveness that is afforded by the design features and measurement capabilities of such a "programmed environment."

The conceptual framework within which the research was undertaken reflects the influence of three prominent classes of interacting factors: (1) team composition, to include personnel or membership characteristics (e.g., number, gender, training, personal history, etc.); (2) team resources, to include facilities and physical setting factors (e.g., hardware, living accommodations, communication networks, etc.); and (3) team objectives, to include performance programs and incentive conditions (e.g., role assignments, pay-off matrices, etc.). These three broad categories of interacting factors are together representative of the range of theoretical and substantive issues addressed in previous team analyses and proposed for prospective team research agendas, with different investigations emphasizing one or the other class.

This paper, then, describes the experimental methodology and representative results derived from studies of such individual and team behavior that were jointly sponsored by the Office of Naval Research and the National Aeronautics and Space Administration. The research methodology includes a laboratory environment that was intentionally designed to facilitate the implementation of a "behavioral program" of daily activities that not only structures the team participants' use of available resources but also provides the framework for the observation and measurement of a comprehensive range of behaviors.

The residential laboratory consists of five rooms and an interconnecting corridor, and it was constructed within a wing of The Henry Phipps Psychiatric Clinic at The Johns Hopkins University School of Medicine. The rooms are enclosed; they have their own walls and ceilings, but no windows, although access to an outside terrace can be granted as a research protocol may permit. The floor plan of the laboratory and its position within the surrounding building shell are presented in Figure 1. Each of the three identical private living quarters (2.6 x 3.4 x 2.4 m) is similar to a small efficiency apartment. Figure 2 shows a subject's sleep area and desk along with storage drawers, intercom, cathode ray tube (CRT) communication console, entertainment console, etc. The sleep surface, which can be enclosed by a privacy curtain, is normally covered so that the upholstery is exposed only during a sleep period. Figure 3 shows the opposite view of the same room. Shown are the kitchen and bathroom-shower combination. A door to the interconnecting corridor is to the left of this view, but on the right side of the room can be seen an unlocked full-sized exit door that leads to the perimeter of the laboratory. Figure 4 shows a representative study participant at work on a creative manual task in a private room. Figure 5 shows one view of the recreation area (4.3 x 6.7 x 2.7 m) that contains a complete kitchen facility along with exercise equipment and games. Figure 6 shows the opposite view of the same area that contains lounge chairs and an exit door to the perimeter. The workshop (2.6 x 4.1 x 2.7 m), presented in

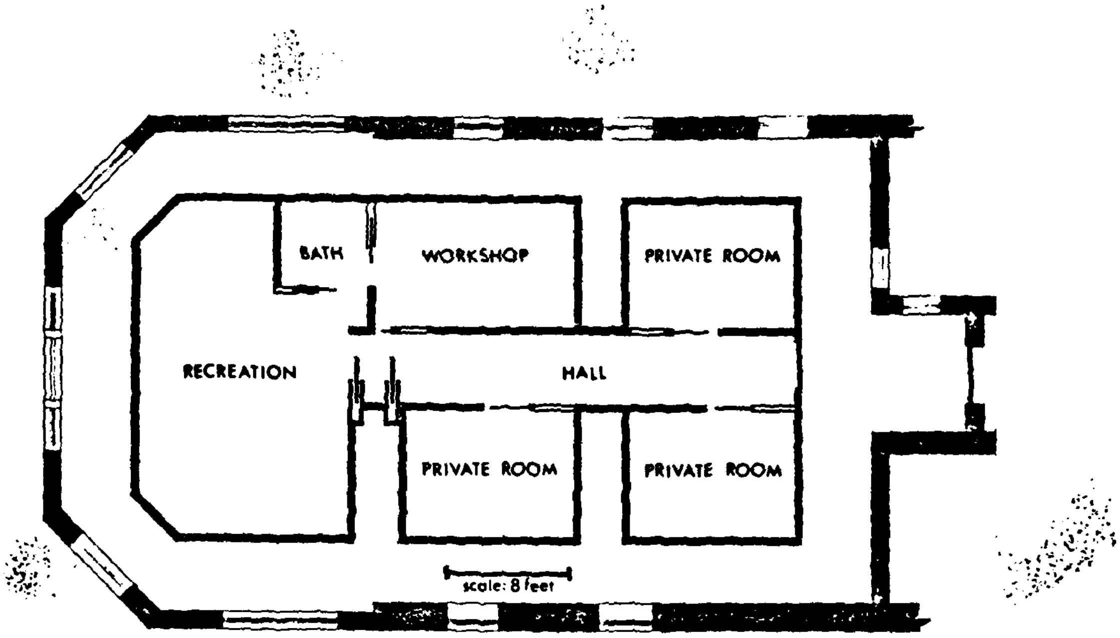


Figure 1. The floor plan of the laboratory, and its position within the surrounding building shell.

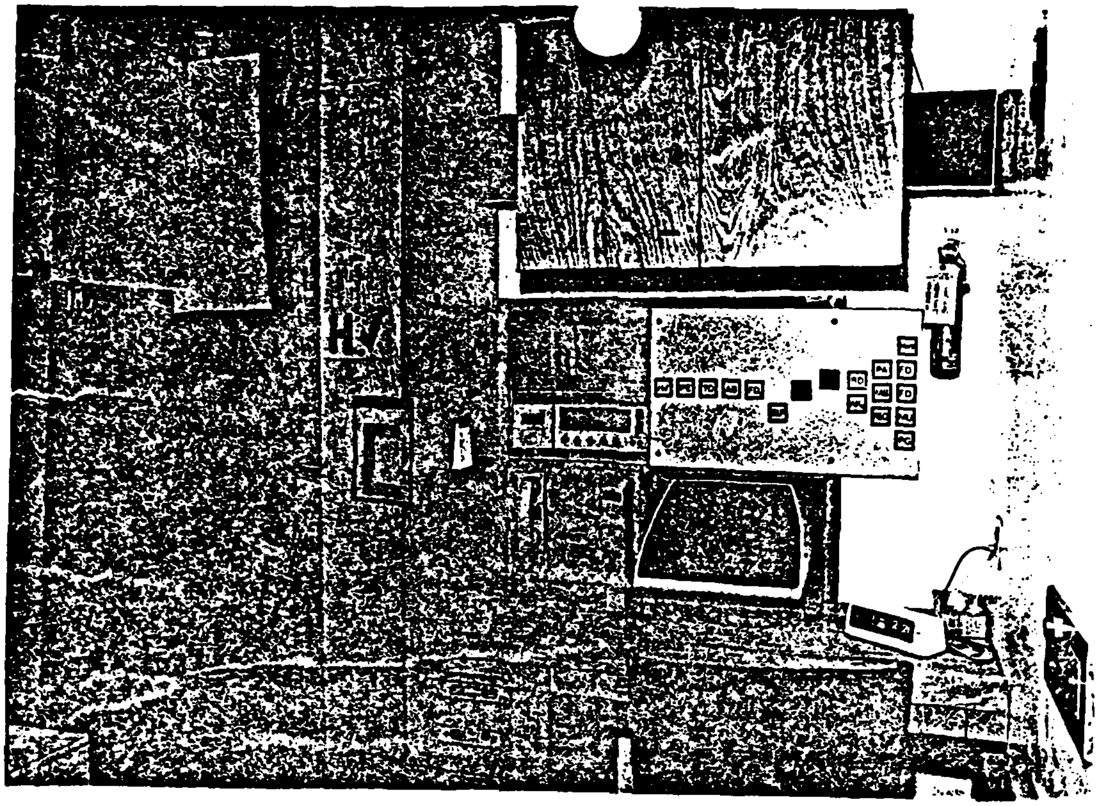


Figure 2. A participant's sleep area and desk along with storage drawers, intercom, cathode ray tube (CRT) communication console, entertainment console, etc.

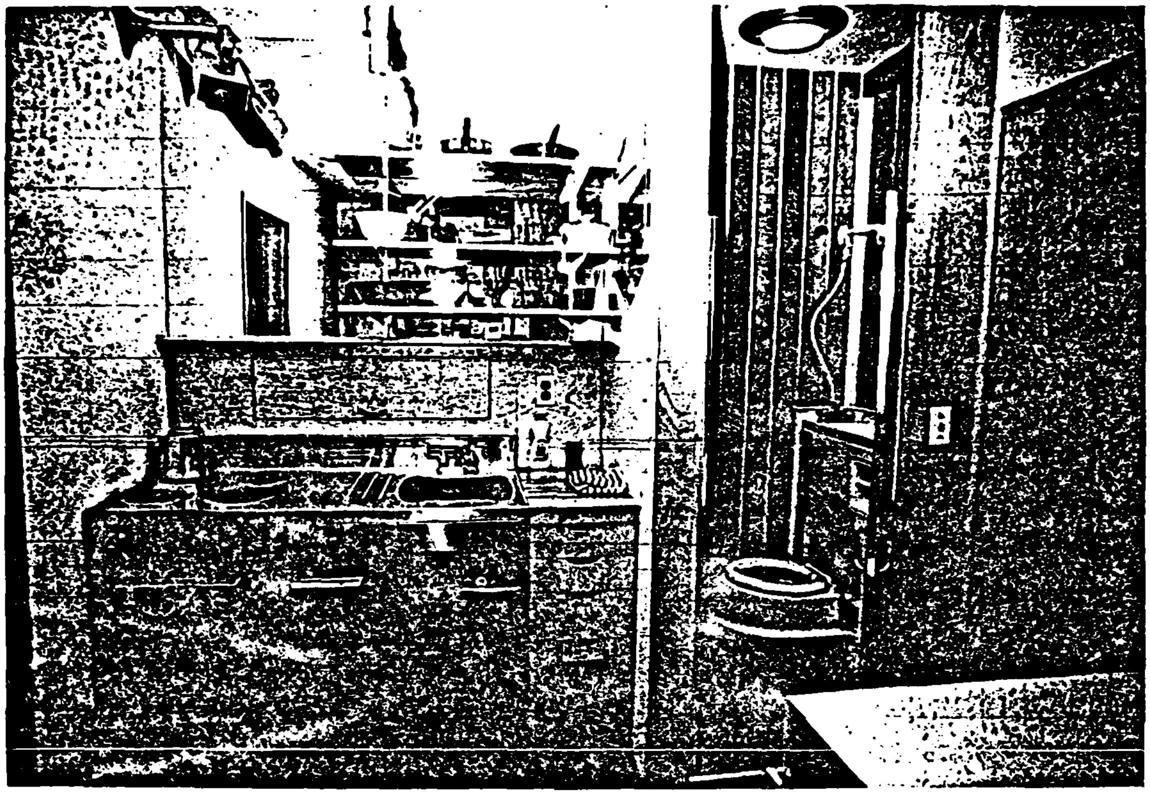


Figure 3. The opposite view of the same private room showing kitchen and bathroom-shower combination.

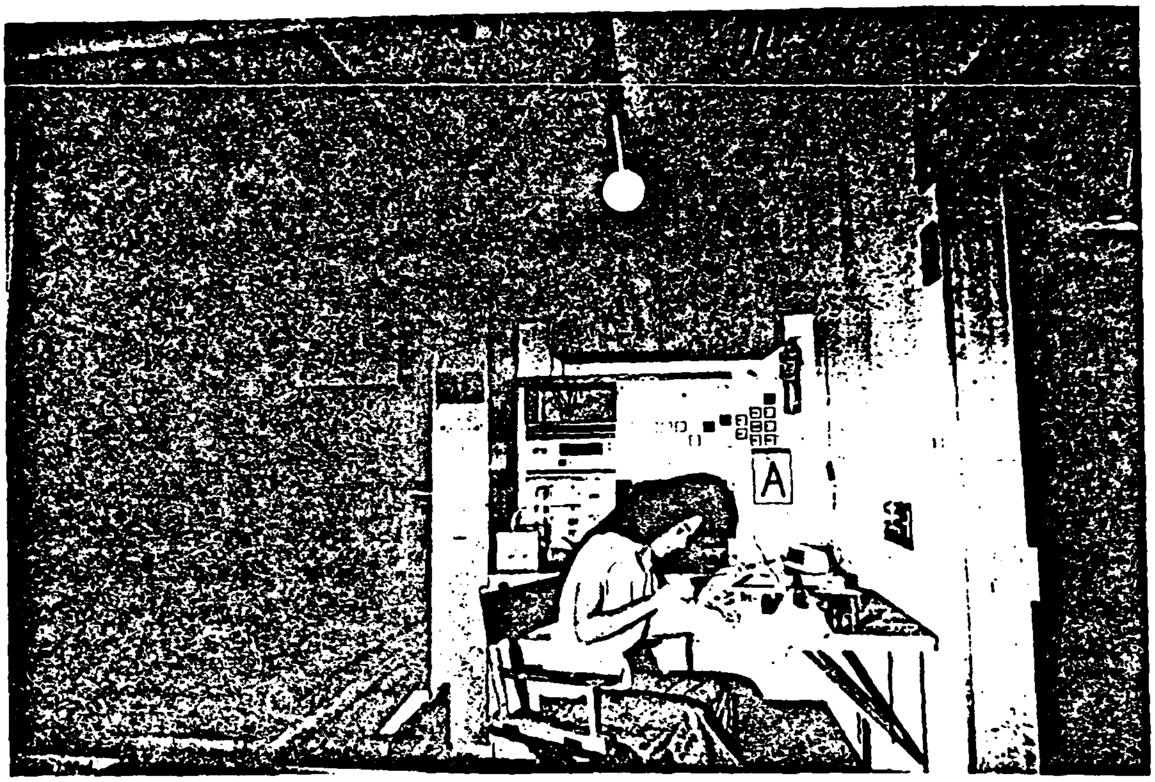


Figure 4. A representative participant at work on a creative manual task within a private room.

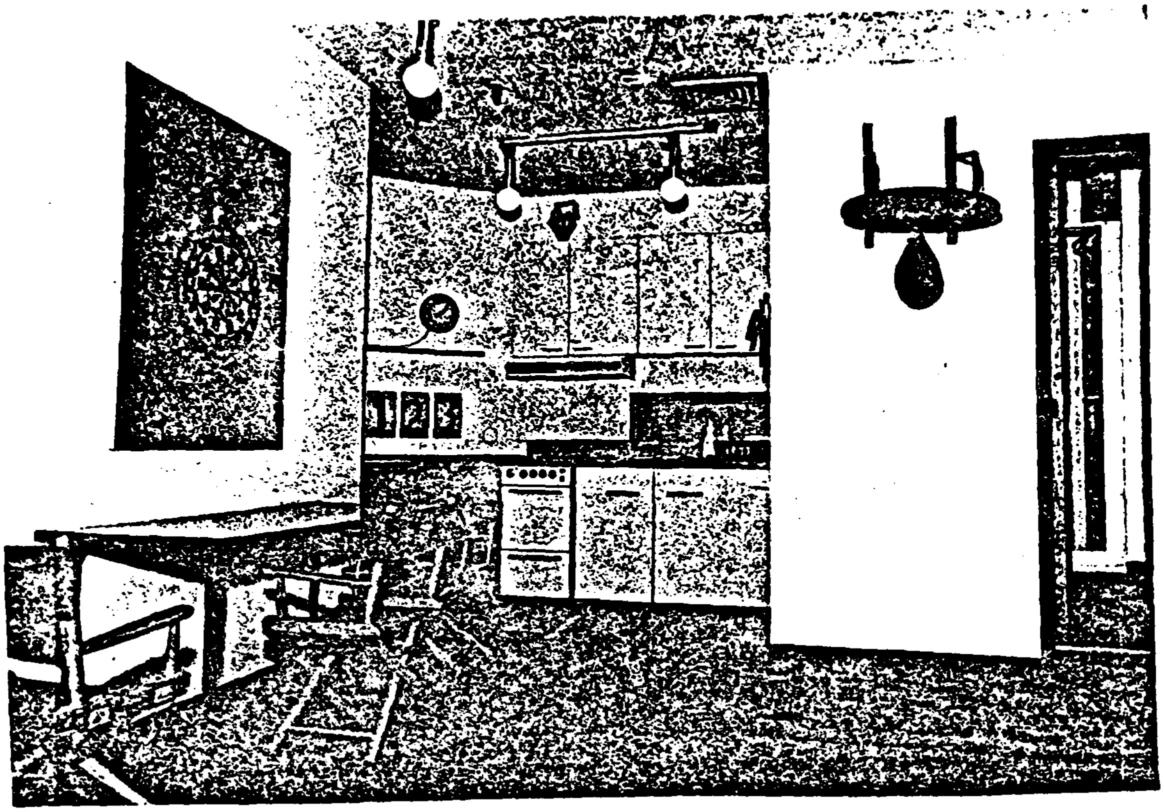


Figure 5. One view of the recreation room that contains a complete kitchen facility along with exercise equipment and games.

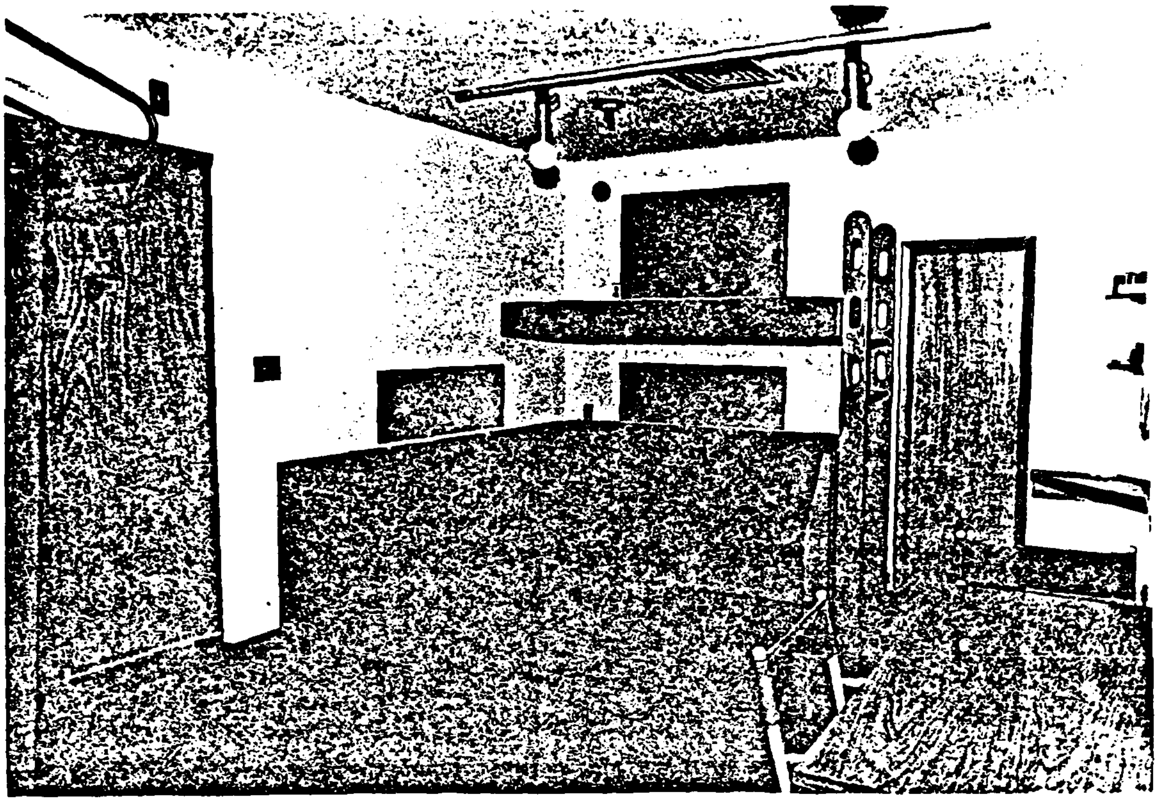


Figure 6. The opposite view of the recreation room showing lounge chairs and the exit door to the perimeter.

Figure 7, contains operator consoles for the individual and team performance tasks. A common bathroom serves the recreation and workshop areas. In summary, the programmed environment can accommodate at least three participants for intensive experimental analyses, and even more study subjects could be added to an experimental protocol by allowing additional members' temporary residence within the recreation area along with their periodic rotations to the privacy of the individual quarters when solitary members move to the recreation area.

The laboratory is "programmed" in the sense that its resources are restricted by design features that electronically regulate access to storage compartments or to areas containing supplies necessary to accomplish a given performance unit.

To structure the team members' use of the laboratory's resources in a disciplined yet meaningful way, a behavioral program was developed to establish and maintain individual and team performance baselines as well as to provide the context for experimental manipulations of performance interactions during extended residential missions. A behavioral program is defined by (1) an array of activities or behavioral units and (2) the rules governing the relationships between these activities. Figure 8, for example, illustrates diagrammatically (1) the fixed and optional activity sequences that characterize a typical behavioral program used to establish baseline performances and (2) an array or inventory of component activities that constitutes such a program. Each box within the diagram represents a distinct behavioral unit and performance requirement, with progression

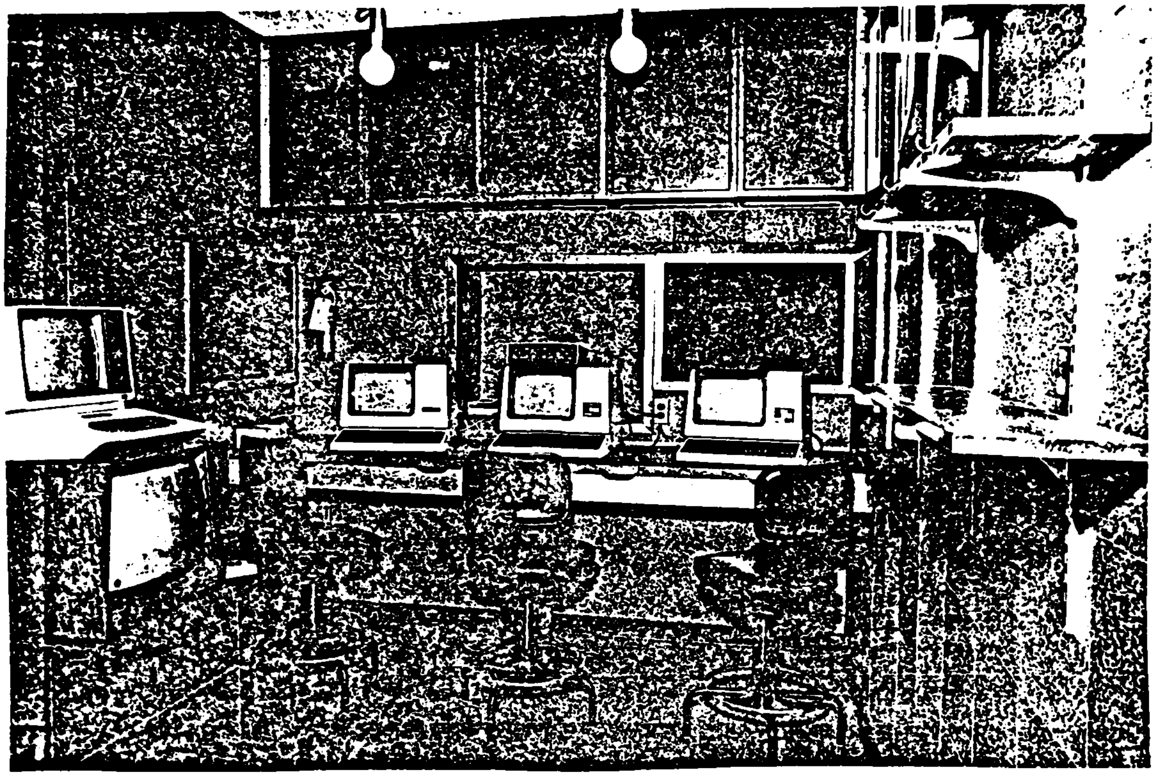
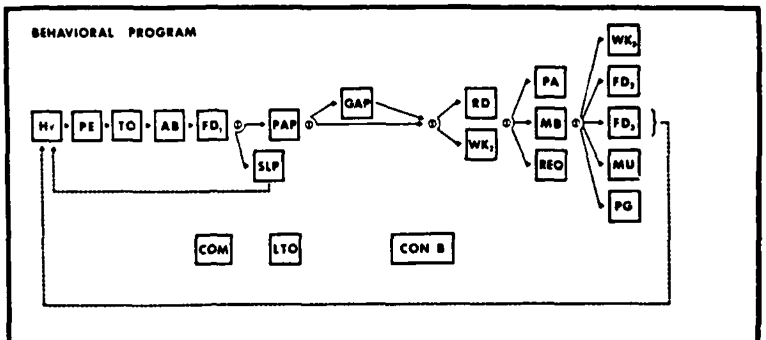


Figure 7. The workshop containing operator consoles for the individual and team performance tasks.



INVENTORY OF ACTIVITIES

NOTATION	FULL NAME	BRIEF DESCRIPTION
H✓	HEALTH CHECK	TEMPERATURE, PULSE, WEIGHT, STATUS REPORT
PE	PHYSICAL EXERCISE	300 CORRECT PRESSES ON AUTOMATED TASK
TO	TOILET OPERATIONS	USE OF PRIVATE BATHROOM AND CONTENTS OF DRAWER CONTAINING TOILETRIES
AB	AUTOGENIC BEHAVIOR	RELAXATION EXERCISES ON CASSETTE TAPE
FD1	FOOD ONE	TWO SELECTIONS FROM A LIST OF LIGHT FOODS
SLP	SLEEP	USE OF BED AND PRIVACY CURTAIN
PAP	PRIVATE ARITHMETIC PROBLEMS	150 CORRECT SOLUTIONS OF ARITHMETIC PROBLEMS
GAP	GROUP ARITHMETIC PROBLEMS	OPTIONAL, CONTRIBUTE CORRECT SOLUTIONS OF PROBLEMS TO GROUP RATIO CRITERION
RD	READING	ACCESS TO BOOK
WK2	WORK TWO	PROBLEMS, EXPERIMENTS, ASSEMBLY PROJECTS
PA	PUZZLE ASSEMBLY	ASSEMBLE A PUZZLE
MB	MANUAL BEHAVIOR	ACCESS TO ART MATERIALS
REQ	REQUISITION	EARN DELAYED DELIVERY OF TREATS
WK3	WORK THREE	ACCESS TO WORKSHOP
FD2	FOOD TWO	PRIVATE MAJOR MEAL
FD3	FOOD THREE	MAJOR MEAL IN RECREATION ROOM, GAMES
MU	MUSIC	EARN A CASSETTE TAPE
PG	PRIVATE GAMES	ACCESS TO SOLITARY GAMES
COM	COMMUNICATION	ACCESS TO INTERCOM
LTO	*LIMITED TOILET* OPERATIONS	*ACCESS TO ESSENTIAL TOILET FACILITIES*
CON B	CONDITION B	CHANGE IN PROGRAM CONDITION

Figure 8. A diagrammatic representation of the fixed and optional activity sequences that characterize a typical behavioral program used to establish baseline performances along with an array or inventory of component activities that constitutes such a program.

through the various activities programmed sequentially from left to right. Finally, all behavioral units are scheduled on a contingent basis such that access to a succeeding activity depends upon satisfaction of the requirements for the preceding unit.

Beginning at the far left of the diagram, the fixed activity sequence is composed of all activities between and including Health Check (H/) and Food One (FD1). The Health Check activity requires the subject to determine his temperature, pulse, and weight and to complete several status questionnaires regarding his mood and reactions to the laboratory environment. He then completes the following activities in the order displayed: Physical Exercise (PE), requiring 300 correct responses on an automated exercise task; Toilet Operations (TO), providing access to the private room bathroom and shower; Autogenic Behavior (AB), in which the subject follows taped relaxation instructions; and Food One (FD1), in which the subject is permitted to select two items from a presented list of 10 "light" foods such as coffee, soup, cereal, etc.

When Food One is completed, the subject is eligible to select <u>one</u> of the following two activities: Private Arithmetic Problems (PAP), requiring 150 solutions of problems presented on a CRT, or Sleep (SLP), providing access to the bed for an unlimited time period of at least 30 minutes. If the subject selects Sleep, he is required to return to the Health Check activity and the fixed activity sequence at the completion of Sleep. This is indicated by the broken line originating at Sleep and terminating at Health Check. In summary, then, the fixed activity sequence was designed to maintain and assess the subject's health if he were otherwise indisposed to engage in the broader selection of opportunities.

The optional activity sequence begins with the choice of Private Arithmetic Problems instead of Sleep. At the completion of that activity, the subject is eligible to select Group Arithmetic Problems (GAP), in which a subject can contribute to a performance criterion that must be satisfied before the group can enter the recreation area. Group Arithmetic Problems can be skipped, allowing the choice between one of the following two activities: Reading (RD), providing at least 30 minutes' access to books contained in a drawer, or Work Two (WK2), in which the subject completes in private various problems, experiments, or assembly projects presented in a drawer. When the selected activity is completed, the subject is eligible to select one of the following three activities: Puzzle Assembly (PA), requiring the subject to assemble a jigsaw puzzle presented in a drawer, Manual Behavior (MB), providing at least 30 minutes' access to art supplies contained in a drawer, or Requisition (REQ), allowing the subject to operate a manual task to earn points that are exchangeable for special privileges. On completion of the selected activity, the subject is eligible to select one of the following five activities: Work Three (WK3), providing access to the workshop, Food Two (FD2), requiring at least 30 minutes and providing the subject with a major meal to prepare and consume within his private room, Food Three (FD3), providing at least 30 minutes in the recreation room by all subjects together, Music (MU), allowing the subject to earn a cassette tape that can be played at any time, or Private Games (PG), allowing at least 30 minutes' access to an assortment of solitary games within a drawer. As indicated by the broken line, once a subject completes his choice among those five activities, he returns to Health Check and resumes the fixed activity sequence. In summary, then, the optional activity sequence allows the subject flexibility in the selection and arrangement of activities, both individual and social.

At the bottom of the diagram are two activities having different selection rules. The Limited Toilet Operations (LTO) activity, which provides access to the bathroom but not the shower, can be selected at any time. The Communication (COM) activity allows access to the intercom for intersubject communications. A subject is permitted to use the intercom to initiate or answer a communication only if he is between any two adjacent activities within the behavioral program. Although the Communication activity is available between any two activities, a conversation requires at least two subjects' simultaneous presence within the Communication activity. Conversing subjects, however, can be located at different sequential positions within the behavioral program. For example, a Communication and conversation might occur when one subject is between Autogenic Behavior and Food One, and another subject is between Manual Behavior and the last column of activities, and so on.

The behavioral program provides a promising solution to the problem of how to structure the resources available to a confined microsociety. The functional interdependencies among activities ensure that performances of value to the welfare of the individual (*e.g.*, Physical Exercise), to the welfare of the team (*e.g.*, social recreation), and to the welfare of a "mission" (e.g., sustained performance effectiveness) occur recurrently over time. These functional interdependencies reflect the "motivational" properties inherent within successive progressions through the program, and all incentives to maintain the overall operational status of the organization can reside within the behavioral schedule itself.

Not only does the behavioral program structure access to resources, but it also makes available for measurement all corresponding activity units. The boundaries between successive activities in the program impose rigor on the assessment of individual and group preferences and effectiveness within those activities. Additionally, the program has the advantage of providing a comprehensive range of variables for observation and measurement. For example, at one level, a subject's performance on arithmetic calculations could be assessed (e.g., errors, response latency), and at another level, a subject's frequency and duration of progressions through the program could be assessed without regard to the intensive analysis of component activities composing such progressions. Moreover, the social status of the microsociety may be assessed by observing the degree of "synchrony" among subjects in the selection and completion of similar activities at the same time. Observations of subjects' communication networks along with the frequency, duration, and quality of dyadic and triadic social episodes would complement synchrony measures. All these factors, then, contribute to a method having considerable and demonstrated power in the analysis of variables which impact upon individual and team performances, especially with regard to the potential interrelationships between the effectiveness of such performances and other contextual aspects encompassing the work environment.

Activities and performance requirements can easily be added to and withdrawn from the behavioral program. For example, it was desired to replace arithmetic calculations with a Multiple Task Performance Battery (MTPB) as a measure of complex human performance. As displayed in Figure 9, the MTPB is composed of the following five subtasks which are presented simultaneously to an individual operator: (1) probability monitoring, (2) arithmetic operations, (3) warning light vigilance, (4) dynamic signal detection, and (5) target monitoring and recognition (3,4). Accurate operation of the subtasks produces "accuracy points" that are cumulatively displayed on the CRT. To "build" this task into the behavioral program, a CRT console was located in the workshop such that only one subject could perform the task at a time, and access to the workshop was made available between any two adjacent activities in the program. When a subject completed a work period in the workshop, he would return to his private quarters and resume the behavioral program at the point of departure. Private Arithmetic Problems and GAP were simply withdrawn from the inventory of activities.

Although performance effectiveness on the MTPB could be made contingently related to access to other "high-value" activities in the program (e.g., social recreation), a different incentive could be applied by relating performance effectiveness to a subject's compensation, and this has been the approach used for recent investigations in the laboratory. Thus, the intrinsic motivational properties of the behavioral program provide the context in which external incentives can be applied where a direct moment-to-moment relationship is desired between performance effectiveness (e.g., quality and quantity) and its immediate consequence. Such an interplay between incentives can be dramatically effective in (1) generating

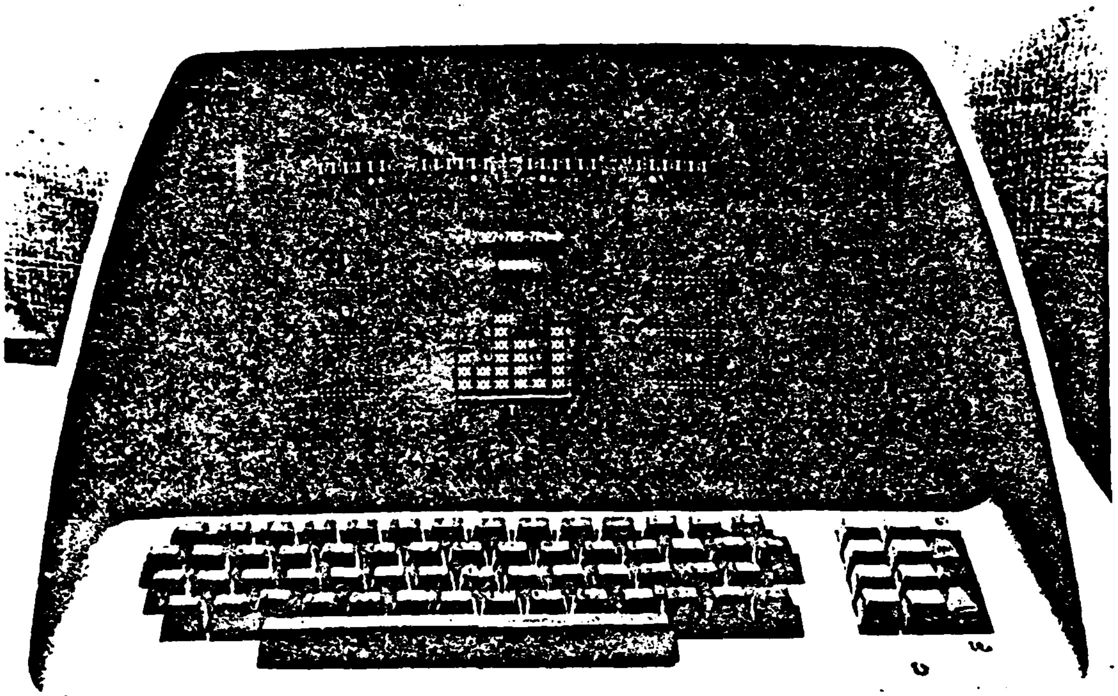


Figure 9. A photograph of the CRT console displaying the five subtasks composing the Multiple Task Performance Battery.

and sustaining complex human performances over extended time periods and in (2) providing the ancillary contextual observations that make performance changes interpretable in terms of a functional analysis.

Subjects respond favorably to the programmed environment and to the behavioral program. With few exceptions, subjects report a sense of heightened accomplishment and productivity in the use of their time while following the program. Although clocks are present in each room of the laboratory, the behavioral program is not oriented to specific time markers, and subjects may drift in wake-sleep cycles according to their personal dispositions. If sleep discipline is required, however, the program could anchor the Sleep activity to a particular time window (e.g., 2300-0600 hours), and remaining time would be filled with programmed activities other than Sleep. Such a procedure has been used successfully in an investigation that required subjects' circadian rhythms to be held constant (5).

Well over one hundred male and female volunteers have participated in the research program to date, and only three subjects have withdrawn from an experiment before its scheduled completion. Almost all participants have a college background, and many are graduates. Acceptance into the research program follows psychological evaluation and detailed orientations to the laboratory and to the behavioral program. The research involves no elements of deception, and informed consent is an integral component of the orientation. Unless otherwise noted, the research results to be summarized herein were based upon anlyses of three-man groups.

Having demonstrated the utility and acceptability of the behavioral program in a series of six-day to sixteen-day residential investigations with two and three subjects, attention was directed to ten-day analyses of the importance of social factors as they affect the status of a three-person microsociety. These analyses showed that social contingencies, which required coordination among group members before access to the recreation area was granted, embedded within the behavioral program could counteract a team's tendency to fragment over time (6). Such contingencies prevented persons with little interest in interacting socially from becoming isolated from the group and, in some cases, from showing a decline in individual performance effectiveness (7). Related experiments showed the reinforcing strength (i.e., appreciation by group members) of triadic social episodes, in contrast to dyadic episodes, and they indicated a relationship between social distance in a triad and time spent in a dyadic situation when social opportunities were limited to pairs of subjects (8). Taken together, these studies indicated that low group cohesiveness increased members' vulnerability to social fragmentation in the absence of specifically programmed triadic contingencies of reinforcement that had the effect of promoting productive social interactions among team participants.

Whereas the preceding investigations were undertaken with incentives inherent within the behavioral program (subjects received a per diem allowance), the next set of studies introduced the interplay between incentives both internal and external to the program as the means of sustaining individual and group behavior. These studies were designed to develop a laboratory model that would allow systematic exploration of individual and social by-products of avoidance incentive conditions. Under a positive incentive condition, "work units" (e.g., physical exercise, manual operations, MTPB performance) were completed by individual team members, and each such unit resulted in a fixed increment to a group account that was divided evenly among the three subjects at the conclusion of the experiment. Under an avoidance incentive condition, however, no money was earned, mission members were assigned a daily performance criterion to satisfy as a team, and failure to reach the criterion resulted in reductions in accumulated earnings. The two incentive conditions appeared in various orders and durations across the series of investigations.

Comparisons between conditions on a number of behavioral program measures dramatized the deleterious effects of the avoidance incentive condition. Disruptive by-products of that condition included (1) interpersonal confrontation and antagonism, especially by high-productivity subjects toward low-productivity subjects, (2) vociferous written and spoken complaints about the schedule, (3) written and spoken hostility directed toward the experimenters, and (4) dysphoric feelings (9). Effects on performance effectiveness during the avoidance condition were demonstrated by one team member who refused to work further on the MTPB in response to another member's falling somewhat behind in his share of work as agreed upon by team participants (10). In contrast, under positive incentive conditions, such disruptive effects did not occur even when extraordinary performance productivity was observed, and a several-day history of negative effects could be overcome by reintroducing the positive condition. These effects emphasized the interaction between heterogeneity in work productivity within an organization and member tolerance and intolerance of such heterogeneity under different incentive conditions.

These foregoing investigations clearly established social variables as fundamental contributors to the overall status of a confined microsociety, and they emphasized the sensitivity of such variables to a range of experimental manipulations having operational significance. Throughout such studies, mission participants were observed to seek social interaction under one set of conditions (e.g., triadic social contingencies and positive performance outcomes) and to withdraw from such interaction under other conditions (e.g., pairing social contingencies and avoidance performance outcomes). Thus, the joining and leaving of a group by mission participants under circumstances encompassing more than a single environmental condition appeared to generate social effects reflecting important dynamic processes requiring systematic experimental analysis.

Accordingly, team performance effectiveness studies were initiated to assess the effects on individual and group behavior of a novitiate participant's introduction into and subsequent withdrawal from a previously established and stable two-person social system. The objectives of these studies were to focus upon (1) the social mechanisms and temporal properties associated with the integration of such a participant into an established team and (2) sources of group disruption or cohesiveness fostered by his or her presence. Additionally, measures of hormonal levels based upon the collection of total urine volumes throughout the course of the studies focused upon changes in the androgen testosterone as an endocrinological index of demonstrated sensitivity to social interaction effects in both animals (11,12) and humans (13). Such a behavioral biological analysis was implemented to provide a more comprehensive assessment of the personal and social impact generated by the introduction and withdrawal of new members with an established group (14).

The paradigm adopted for experimental analyses of effects of changes in group size and composition was as follows. A two-person group resided for ten successive days within the programmed environment, and members of that dyadic team operated performance tasks for their earnings. During the course of that ten-day period, a third "novitiate" participant was introduced into the programmed environment for several successive days, thereby increasing the size of the group from two to three members. A typical "introduction" period with three group members lasted four days, and it usually began on Day 4 or Day 7 of a ten-day experiment.

The rule conditions of the behavioral program that were associated with the novitiate's entrance into the group differed across successive investigations. In some studies, the novitiate received a per diem allowance, and he was not required to work for compensation, although he was permitted to contribute to the performance tasks that advantaged the two established group members. In other studies, the novitiate was required to work for compensation by competing with the two other group members for access to the single MTPB console located within the workshop. Finally, the series of investigations was undertaken with both male and female novitiates and, in some cases, with novitiates and dyadic members who had previously participated in a residential study.

In studies where the novitiate's presence primarily served as additional social stimulation for the established dyad and as a source of information regarding current events outside the laboratory, the two-person group showed a resistance to granting the novitiate permission to work, even when such work would have provided relief from operating a demanding task. Importantly, however, as the three-person condition continued over days, novitiates were observed to contribute to work productivity to a degree that was almost equivalent to the productivity of the dyadic members. Since there were no external incentives for a novitiate's work in these first introduction studies, these findings emphasized the influence of social processes alone in maintaining performance productivity, at least within these cohesive group situations. Finally, novitiates showed daily urinary testosterone, as determined by radioimmunoassay (15), at the upper and lower boundaries of the standard range, but the absence of baseline levels precluded the interpretation that active social processes had governed such effects.

Transitions between two-person and three-person conditions were not always smooth in groups where the novitiate had to work the MTPB for compensation. When a novitiate forcefully intruded himself into the dyad's customary work schedule, his testosterone levels rose or fell generally in close relationship with his success or failure, respectively, to gain and maintain access to the MTPB station according to a schedule that was least disruptive to his wake-sleep cycles as determined during several baseline days preceding his introduction into the group. When sleep discipline was imposed, and when a novitiate was cooperative in negotiating an orderly sequence of using the MTPB, notable changes in testosterone were not observed in any team participant. Finally, when a female novitiate was introduced into a two-man group, wake-sleep cycles and work periods were erratic throughout the three-person condition. Such effects were associated with the absence of notable androgen changes, even by a dyadic member who, as a novitiate in an earlier study, had successfully maintained his wake-sleep cycles and had shown a striking increase in testosterone when he joined the group.

The significance of these behavioral-biological interactions is to be understood in terms of the completeness of the resulting account of effects of the experimental variable, *i.e.*, the introduction of a novitiate into an established group. From such an account, principles emerge that can facilitate the development of technological guidelines having the purpose of minimizing disruptive effects of transitions in group size and organization. With regard to the relevance of the observed interactive endocrinological relationships, the adaptive significance of any hormonal response can perhaps best be interpreted in terms of the consequences of that response at the metabolic level of functioning. Although research on the androgens has typically emphasized reproductive functions, it is well established that testosterone has potent "anabolic" properties, promoting protein synthesis in muscle and many other tissues (16,17,18) and potentiating some effects of insulin on carbohydrate metabolism (19). Whether these "anabolic" effects of testosterone and the androgenic metabolites play any appreciable role in general organic or energy metabolism must, of course, await clarification by further investigative analysis.

The next series of experiments demonstrated the extension of the research paradigm from analyses of "introduction" effects to the analysis of "replacement" effects. Whereas the previous investigations changed group size as an experimental variable or treatment, the most recently initiated studies held group size constant to evaluate effects of replacing a member of an established three-person group with a novitiate participant. These replacement analyses, then, involved important elements of continuity with the earlier studies in the manner of being systematic replications of those investigations. In a research strategy based upon systematic replications, as compared with exact or direct replications, effects of the experimental variable or treatment are demonstrated by affirming the consequent (20), in which case each successive replication incrementally contributes to an understanding of effects that can be reliably attributable to the antecedent condition (*e.g.*, introductions or replacements). The generality of the behavioral processes is assured by showing similar relationships across a broad range of circumstances (*e.g.*, subjects, order and duration of experimental conditions, performance tasks, group size, etc.). This research strategy as adopted by the programmed environment unit has proved to be most productive and economical, especially in light of the expense and staffing effort required to undertake programmed environment investigations.

A typical replacement investigation proceeded as follows. An original three-person group resided in the programmed environment for five successive days. At the end of Day 5, one of the original group members was withdrawn, and he was replaced by a novitiate participant who, along with the remaining two original members, formed a new group for the next five successive days. Consecutive studies differed in terms of (1) the decision rule by which an original group member was withdrawn, (2) the number of baseline days that came before group formation, and (3) the type of performance tasks that the group members operated for compensation.

For the first replacement experiment (REPL 1), three-person group members resided in their private rooms for a two-day baseline "alone" period during which time access to the intercom, to social activities, and to the MTPB work station was prohibited. This two-day period provided a necessary hormonal reference against which to assess endocrine responses in relationship to initial group formation. On Day 3, all activities previously prohibited were made available to the group, and each member was required to operate the MTPB for individual compensation. As in the introduction experiments, there was only one MTPB console located within the workshop, and subjects occupied the workshop singly on a self-determined rotational basis. This procedure, then, permitted an evaluation of the manner in which subjects occupied the work station (e.g., duration of work periods, time-of-day of work periods, etc.) as one of the principal dependent variables of the experiment.

At the end of Day 5, whoever of the three mission members had earned the fewest MTPB performance points, totalled across Days 3-5, was withdrawn from the experiment. This decision rule was known by the group members before the experiment began. The novitiate participant entered the programmed environment on Day 6, which was a solitary baseline day for all three subjects. On Day 7, the newly formed team had access to intercom communications, social activities, and the MTPB work station that continued to be available throughout Days 7-10. Thus, the two ten-day participants were required to adjust to the replacement of an original member, and the novitiate member was required to adjust to his entrance into an established unit whose members shared a history of having competed successfully to maintain high levels of performance effectiveness.

Figure 10 presents time of day spent working on the MTPB for all subjects across successive days of the experiment when access to work was permitted. The novitiate participant is identified as "S4." Throughout Days 3-5, subjects alternated in their occupancy of the work station, with uninterrupted work periods ranging from 2 hours (*e.g.*, S1, Day 3) to 9 hours (*e.g.*, S2, Day 4). The lengthy work period exhibited by S2 on Day 4 was related to his attempt to remain competitive after having worked only 2 hours on Day 3. When the novitiate (S4) began to work on Day 7, having replaced S2, he initially preempted the work station for at least nine uninterrupted hours of MTPB performance. That the other group members were unappreciative of this intrusion was indicated quantitatively by the negative interpersonal ratings assigned to S4 during the Health Check activity. Thereafter, the novitiate and the remaining group members alternated occupancy of the work station, with S3 clearly showing work times later in the day in contrast to his work times during Days 3-5. Neither the original group nor the reformed group showed stability across days of work times, and this outcome is perhaps attributable to the competitive contingencies for individual compensation that were present throughout all work days.

Figure 11 shows time of day spent sleeping for all subjects across

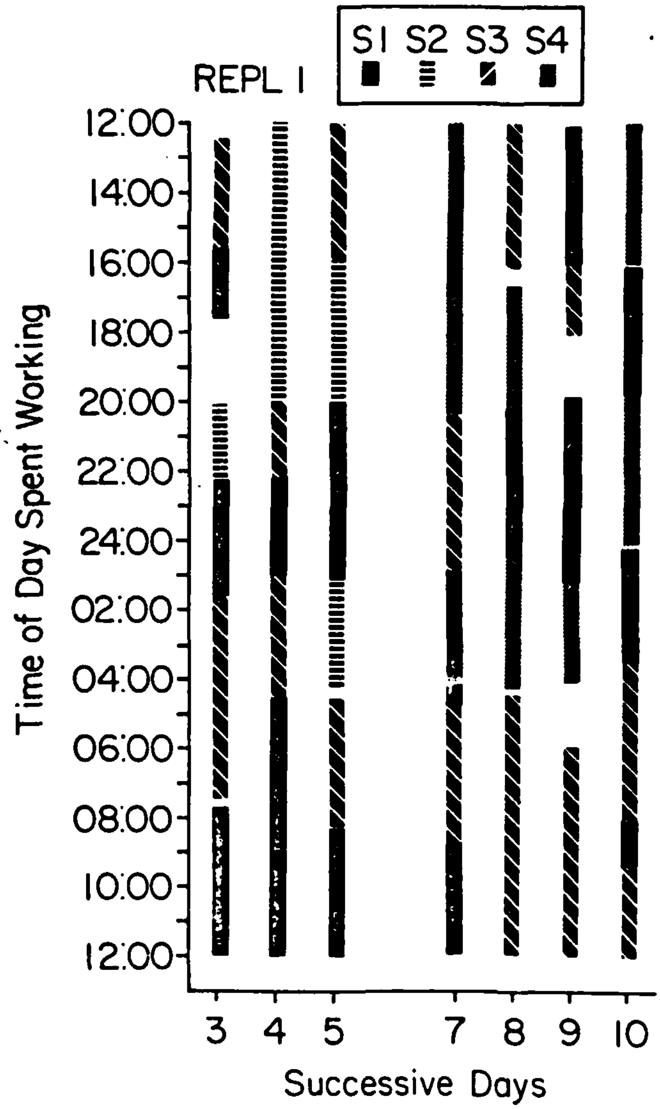


Figure 10. Time of day spent working on the individual Multiple Task Performance Battery for all subjects across successive days of the experiment (REPL 1) when access to work was permitted.

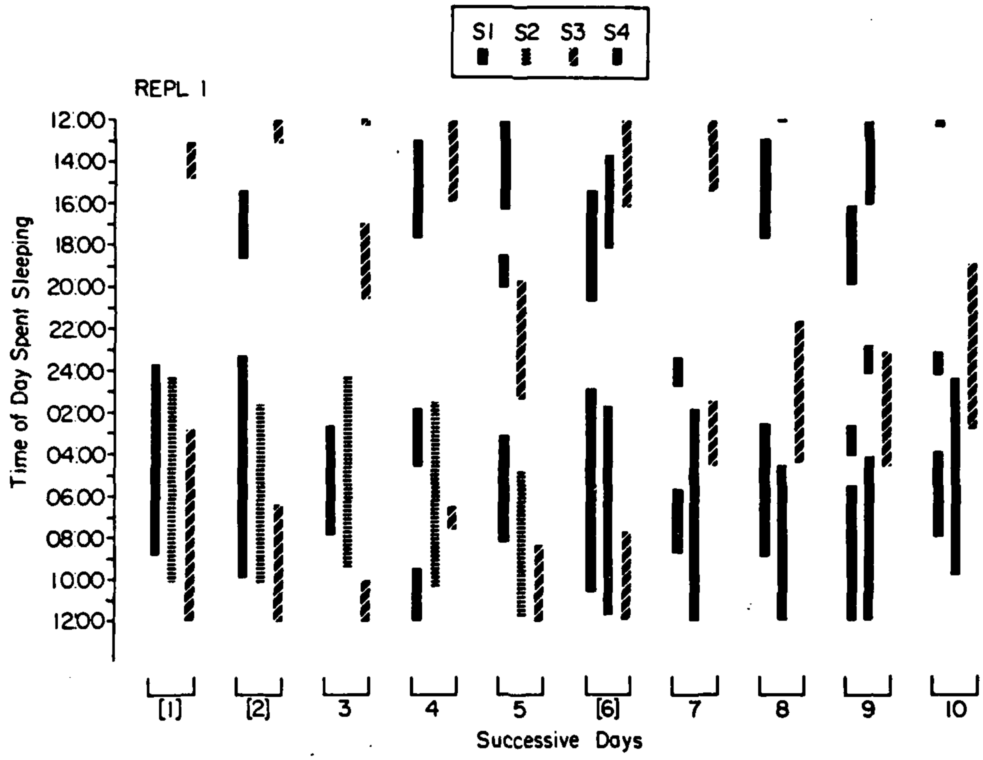


Figure 11. Time of day spent sleeping for all subjects across successive days of the experiment (REPL 1). Bracketed days [1] , [2], and [6] were baseline "alone" days.

successive days of the experiment. Comparatively stable sleep patterns were exhibited only by S2 who showed uninterrupted sleep episodes beginning between 2400 and 0500 hours across Days 1-5. During the same five-day period, Subjects 2 and 3 almost always showed erratic sleep episodes that differed across days in time of day of occurrence, frequency, and duration. Similar erratic patterns persisted during Days 6-10 when S2 was replaced by the novitiate (S4). Importantly, the novitiate showed the most consistent sleep periods across days, and S3 showed a clear reorientation in his sleep episodes that persisted throughout Days 7-10. These latter effects reflect the readjustments that were required by at least one original group member when the novitiate became a working participant during Days 7-10 of the experiment.

Figure 12 shows total urinary testosterone for all subjects across successive days of the experiment. With respect to the orginal group members, S2 showed testosterone values that were somewhat lower than the other two participants. Importantly, these comparatively lower values were evident during the first two baseline days of the experiment. When group members commenced working on Day 3, S2's values increased somewhat over baseline levels, but they continued to be below the values exhibited by the other two members across Days 3-5. Significantly, S2 was the mission member who did not compete successfully to remain within the experiment for ten days, and he was withdrawn at the conclusion of Day 5. Finally, across Days 7-10, testosterone levels progressively declined for S3 in relationship to his shift in work and sleep times. This latter effect confirms the outcomes observed in the introduction studies, and it demonstrates, by systematic

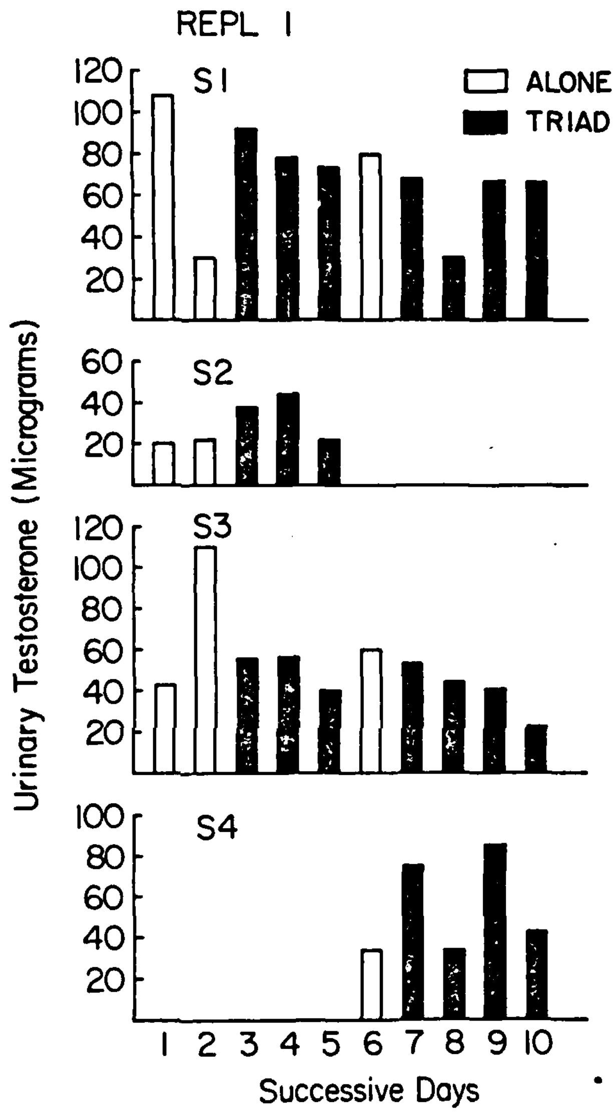


Figure 12. Total urinary testosterone for all subjects across successive days of the experiment (REPL 1).

replication, the generality of the behavioral-biological processes governing such effects.

The experimental design plan of the second replacement analysis (REPL 2) was similar to the first with two major differences. First, the novitiate group member was a female who had previously participated in an unrelated ten-day residential experiment, and she had almost 60 hours' practice on the MTPB. Second, to provide more days for competition to remain in the experiment and a longer history of sustained performance effectiveness by two group members prior to the novitiate's entrance, no initial baseline was programmed. The novitiate, then, entered the environment at the beginning of Day 6, which was a baseline day for all subjects, with more experience in the laboratory than the two other group members. Thus, the two ten-day participants were required to adjust to the replacement of an original group member by a person having extensive programmed environment experience.

Figure 13 presents time of day spent working on the MTPB for all subjects across successive days of the experiment when access to work was permitted. The novitiate participant is identified as "S4." Throughout Days 1-3, subjects alternated occupancy of the work station in an erratic fashion within and across days, with work periods lasting between 1 hour (*e.g.*, S1, Day 1) and 8 hours (*e.g.*, S1, Day 3). Subject 3 voluntarily withdrew from the experiment during Day 3, reasoning that his performance would not result in his participation beyond Day 5. Since the novitiate was not scheduled to appear until Day 6, a baseline day for all subjects, the two remaining subjects were programmed with baseline days on Days 4 and 5. This preserved

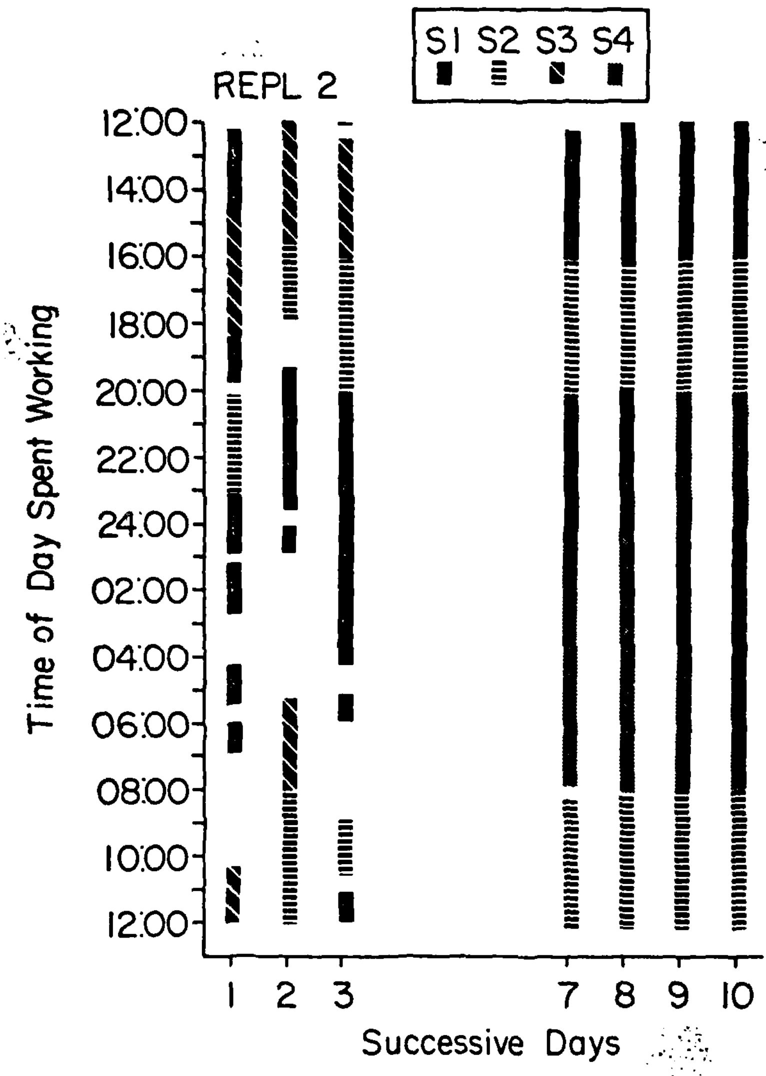


Figure 13. Time of day spent working on the individual Multiple Task Performance Battery for all subjects across successive days of the experiment (REPL 2) when access to work was permitted.

the integrity of the experimental design plan in relationship to analyses of three-person working groups. In striking contrast to work times during Days 1-3, work times during Days 7-10 were orderly and precise. The pattern for Day 8 is identical to Day 7, and the pattern for Day 10 is identical to Day 9. Throughout Days 7-10, all subjects occupied the work station for eight hours each day.

These data show the impact of an experienced person, who exhibited assertiveness and leadership, on an established group whose members had previously competed successfully to remain within the experiment. Although the two-person group followed the suggestions, if not the directions, of the novitiate, S4 received negative interpersonal ratings on the Health Check questionnaires.

Figure 14 presents time of day spent sleeping for all subjects across successive days of the experiment. Although sleep times were perhaps not as erratic as those in the previous experiment, only S2 showed patterns that were somewhat consistent across all mission days. Additionally, the novitiate shifted her sleep pattern on Day 8, and she thereafter commenced sleep periods in the early hours (*e.g.*, 1200) of an experimental "day." Finally, the stable sleep patterns exhibited by all subjects on Days 9 and 10 corresponded to stable work periods also observed on those two final mission days.

In all previous investigations, the coordination required of mission participants was reflected in the sequential use of the work station and in the program synchrony necessary for subjects to meet together in the

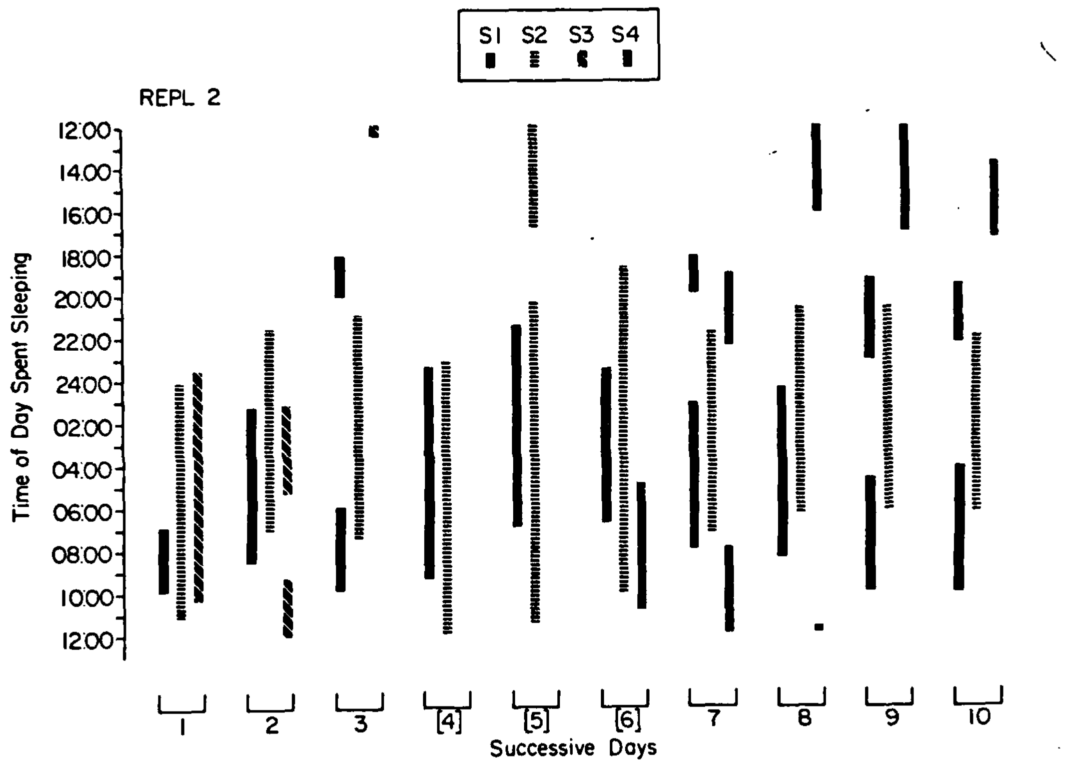


Figure 14. Time of day spent sleeping for all subjects across successive days of the experiment (REPL 2). Bracketed days [4], [5], and [6] were baseline "alone" days.

recreation room. In the next replacement investigation (REPL 3), however, a team performance task was introduced into the research protocol that systematically replicated the preceding analyses with a task demanding far more stringent coordination requirements.

The team performance task is an expanded version of the single-operator MTPB that previously served as the project's principal performance assessment tool. The Team MTPB (TMTPB) involves three operator consoles, each console presenting the identical display of the five task components (see Figures 7 and 9). The parameters of these tasks were modified to a difficulty level such that the concurrent inputs of three operators were required to avoid information overload and to produce maximum performance effectiveness per unit time. The "team" aspect of the task is reflected by the interlocking response demands associated with the probability monitoring subtask, and it is embedded within the context of the remaining four individually solvable subtasks. The team subtask requires the detection of a bias that was recurrently presented on any one or more of the four probability monitoring scales. Importantly, the operator inputs to the system to "correct" a bias requires each of the three operators to press the corresponding "correct" keyboard character within 0.6 sec of the first such keyboard entry. Although correction of a bias produces increments in accuracy points, a team's failure to detect a bias results in subtractions to accumulated points. The team task, then, requires (1) processing of symbolic information (_i.e._, the detection of a bias), (2) sharing information by communications among team members (_e.g._, One operator may say "Bias on one. Ready...Go."), (3) coordination of a response (_i.e._, three response inputs within 0.6 sec), and

(4) sustained vigilance to avoid loss. This team task reflects the major performance dimensions considered to be crucial to developing methods for quantitative analyses of the interrelationships between individual and team performance effectiveness (21).

The ten-day experiment began with a three-man team whose members were new to the programmed environment and to the TMTPB. Participants had been acquainted with the individual MTPB during an orientation session, but acquisition of the TMTPB occurred for the first time on Day 1 of the experiment. For remuneration for participation, the team operated the TMTPB to a performance ceiling of 5000 accuracy points each day, requiring 6-9 hours of work to accomplish. The team members decided among themselves the manner of distributing the performance demands of the individual and team subtasks.

At the end of Day 5, one of the three original team members was withdrawn from the experiment. Initial team members began the study with the understanding that one participant would be withdrawn, but they were not given the decision rule by which that choice would be made. At the beginning of Day 6, then, a novitiate participant was introduced into the programmed environment. To accommodate this transition, the three participants followed the behavioral program in their private quarters on Day 6, but without access to the TMTPB, intercom communications, and social activities. On Day 7, the novitiate member joined the team as the replacement participant, and this newly formed team operated the TMTPB on Days 7-10.

Figure 15 presents time of day spent working by the team across

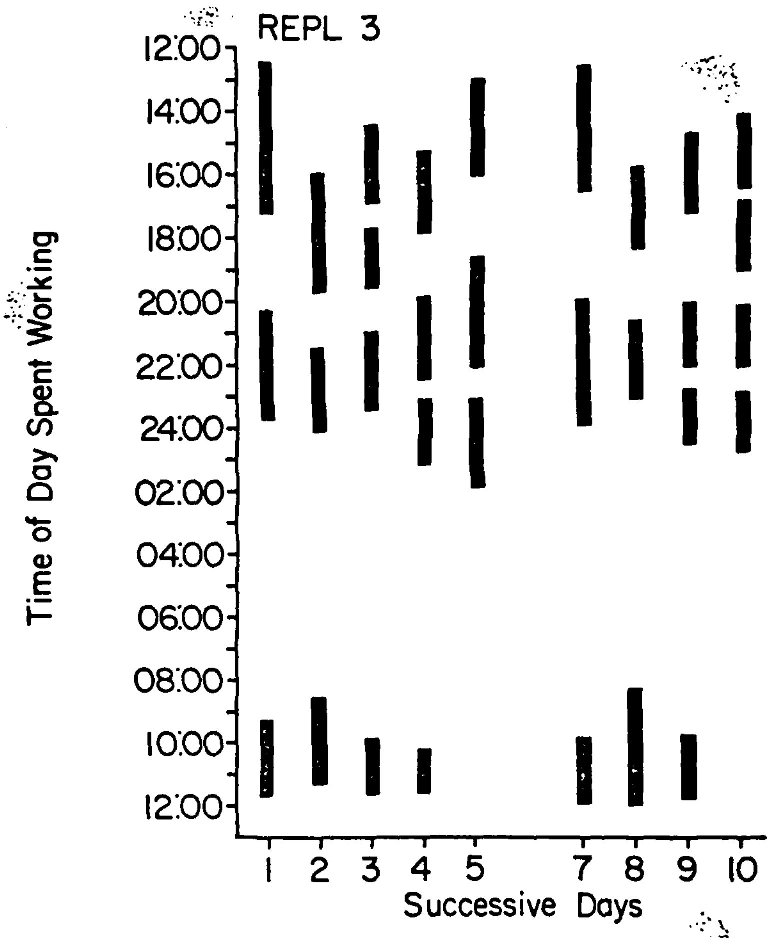


Figure 15. Time of day spent working on the Team Multiple Task Performance Battery across successive days of the experiment (REPL 3).

successive days of the experiment. This figure shows that three or four work periods occurred each day, and they ranged in duration from two to five hours. Although the time of day associated with work periods differed across days, work was not generally observed between 2400 and 0800 hours of a day. Finally, the pattern of work that the initial team adopted was also observed during the final four days of the study with the reformed team.

Figure 16 presents time of day spent sleeping for all subjects across successive days of the experiment. The novitiate participant is identified as "S4." Although the behavioral program was not oriented to time markers, sleep periods were generally stable across successive days for both original and reformed teams. When drift in sleep onset time occurred across days, all members of a team drifted in concert with each other.

The dynamics of the components of the individual and team subtasks differed. Figure 17 shows, for example, points earned on the individual subtasks of the TMTPB across successive work periods. This figure graphically shows smooth initial acquisition (Segment 1) and reacquisition (Segment 2) trends on the individually solvable subtasks. Additionally, it shows that the reformed team exhibited degraded performance during the first two work periods of Segment 2 and that performance reacquisition was more rapid than was acquisition by the original team. Performance on the individual subtasks was degraded despite the presence of two team members who had a combined total of almost eighty hours' practice on the TMTPB. That such performance degradation was not associated with social disruption was indicated by the absence of negative ratings toward the novitiate as

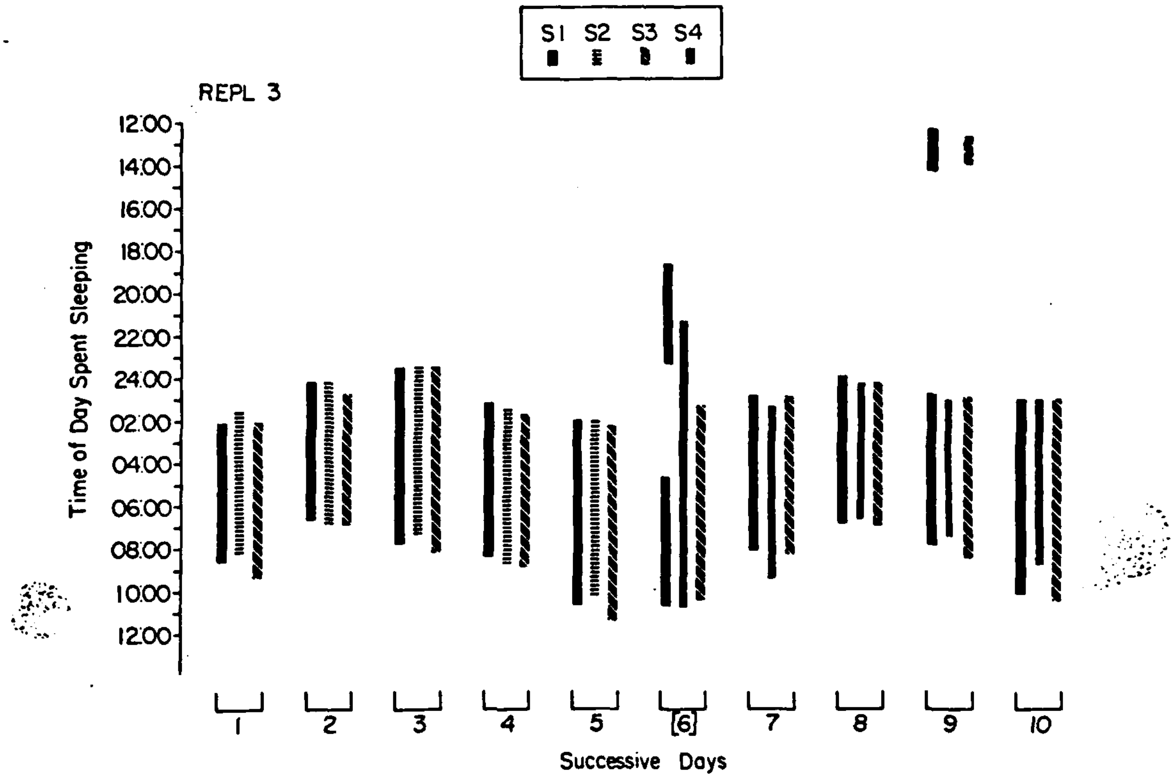


Figure 16. Time of day spent sleeping for all subjects across successive days of the experiment (REPL 3). Bracketed day [6] was a baseline "alone" day.

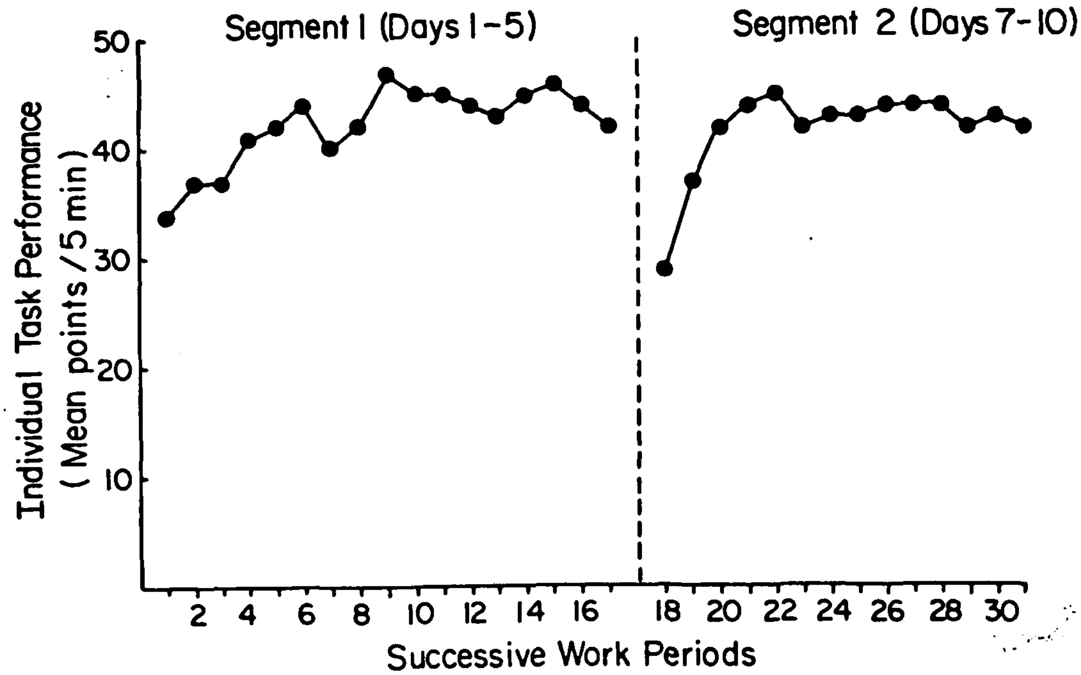


Figure 17. Points earned on the four individual subtasks of the Team Multiple Task Performance Battery across successive work periods.

determined from recurrent Health Check assessments.

Figure 18 shows points earned on the team subtask of the TMTPB across successive work periods. In contrast to individual task performance, performance effectiveness on the team task was erratic, even though a trend toward improved team performance is graphically apparent for initial (Segment 1) and reformed (Segment 2) teams.

These observations suggest that improvement in combined individual and team performance effectiveness over successive work periods was attributable, in large part, to improvement on the contextual individual subtasks. Additionally, preliminary analysis shows that improvement on the team subtask for the orginal team (Segment 1) was attributable to a progressive "sharpening" of the discrimination in the manner of fewer false alarms over successive work periods. Such was not the case, however, for the reformed team (Segment 2). During Days 7-10, whatever improvement there was on the team subtask was attributable to fewer missed biases and not to fewer false alarms. Thus, a clear shift occurred in the operation of the team subtask between Segments 1 and 2, despite the overall trend toward improved performance across both segments.

The performance shift observed on the team subtask between Segments 1 and 2 suggests the involvement of a more complex process of acquisition and reacquisition than repeated practice. Such a process might involve "solution strategy rehearsals" among team members for responsibility in operating the several subtasks. For example, when the novitiate joined the team, the two original team members likely assumed rotational responsibility for monitoring

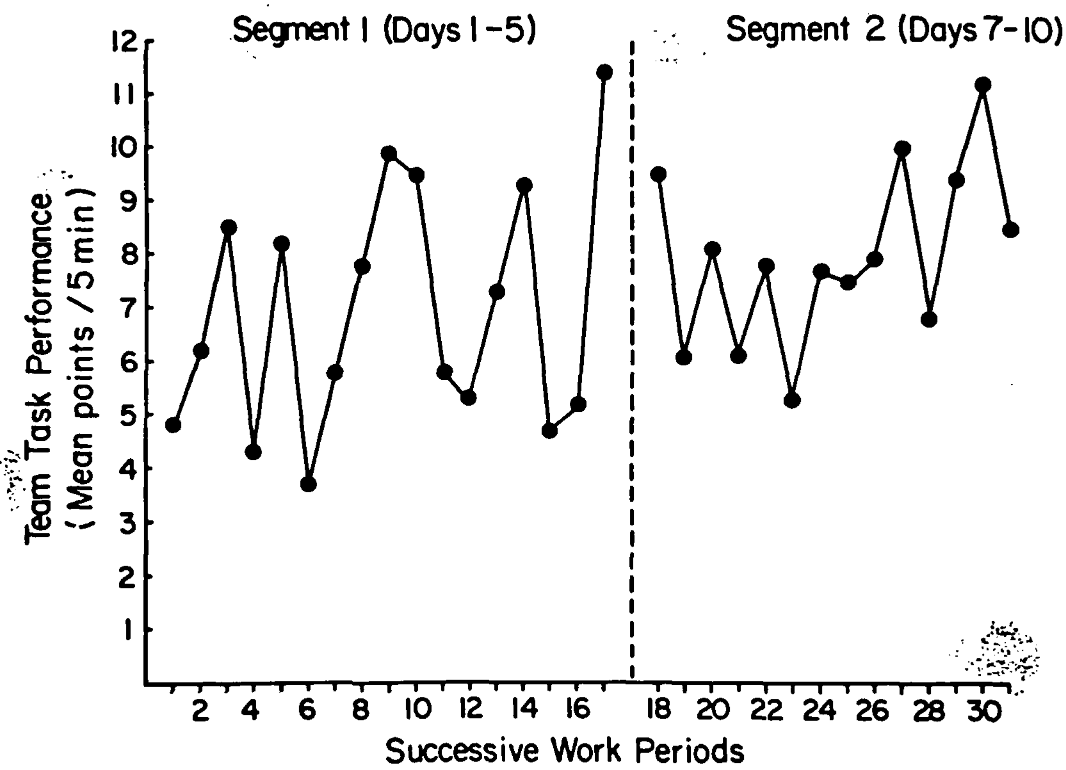


Figure 18. Points earned on the team subtask of the Team Multiple Task Performance Battery across successive work periods.

the team subtask to avoid potential losses while the novitiate mastered the discrimination. Finally, the prominent involvement of such rehearsals and rotations is further indicated by the fact that progressive improvement in overall performance effectiveness was attributable, for the most part, to improvement between successive work periods rather than to improvement within work periods.

Much more needs to be learned about those strategies and rotations and their dynamic interplay with individual and team performance effectiveness. Against the background of the introduction analyses that showed an established team's resistance to accepting a novitiate's work, the present study shows that a novitiate's lack of skill on a task can perhaps be masked by experienced team members who are unwilling to tolerate even a temporary degradation in overall team performance effectiveness. The penalty of such a strategy is to be understood in terms of the constraints on redundancy of skills that could result in even more drastically degraded performances under conditions of further replacements of the original team members. By developing quantitative (*i.e.*, computer assisted) approaches to assessing the moment-to-moment performances of team members, the relative contributions of individual member performance to the terminal steady-state of the system can be characterized. At the very least, such a characterization would suggest intervention guidelines or pre-training schedules that would ensure the most effective balance between individual and team performance effectiveness and subtask proficiency under the various conditions of membership turnover.

CONCLUSIONS

The objectives of this research project on individual and team performance effectiveness have focused upon the development of principles and procedures relevant to the selection and training of mission personnel, upon the investigation of preventive monitoring and corrective procedures to enhance mission performance effectiveness, and upon the evaluation of countermeasures to the potentially disruptive effects of high-demand and stressful performance, interpersonal, and physical environments. Initial research activities were directed toward the design and development of an experimental microsociety environment for continuous residence by three-person groups of human volunteers over extended time periods under conditions that provided for programmable performance and recreational opportunities within the context of a biologically and behaviorally supportive setting. Studies were then undertaken to analyze experimentally (1) conditions that sustain group cohesion and productivity and that prevent social fragmentation and individual performance deterioration, (2) motivational effects produced by the programmed incentives maintaining individual and team performance requirements, and (3) behavioral and biological effects resulting from changes in team size and composition. The significance of these investigative endeavors is to be understood in terms of emergent motivational, social-interaction, and group composition principles having practical relevance to the establishment and maintenance of operational mission performance effectiveness.

In this latter regard, the results obtained from these small-group studies clearly established the applicability and generality of behavioral technologies and methodologies to the experimental analysis of individual and team performances within the context of a human microsociety. Additionally, the development of behavioral programming techniques was demonstrably effective in generating and maintaining such individual and group performances for unobtrusive monitoring and measurement with precision and regularity over time. Furthermore, the interplay between incentives both internal and external to the program provided the occasion for observations of performance in relationship to realistic incentive schedules. The application of such contingency management principles, along with the technological guidelines that provided the basis for design and development of the programmed microsociety environment, were shown to be capable of sustaining individual and team performance effectiveness and group cohesion without notable biological or behavioral disruption under conditions of spatial restriction, social separation, enforced intimacy, and high performance requirements.

More specifically, the results of these studies showed that both individual and group productivity can be enhanced under confined microsociety conditions by the application of contingency management principles to designated "high-value" component tasks embedded within the overall performance program. Similarly, group cohesiveness can be promoted, and individual social isolation and/or alienation (*i.e.*, group fragmentaton) can be prevented by the application of contingency management principles to social-interaction segments of the performance program.

Conditions that were found to result in progressive deterioration of individual and team performance effectiveness included aversive programming contingencies such as loss of accumulated earnings. The by-products of aversive schedules that emerged under such circumstances were found to be detectable and quantifiable in measures of verbal performance (e.g., behavioral program ratings), interpersonal performance (e.g., verbal confrontation and aggression), work performance (e.g., diminished productivity), and team morale (e.g., irritability and dysphoric mood). In contrast, positive incentive schedules effectively counteracted the disruptive consequences of aversive contingencies while at the same time supporting high work productivity free from negative side-effects.

Related research results emphasized the prominent involvement of behavioral and biological processes that were functionally related to adjustments and reactions when changes occurred in group size and team composition. The experimental analysis of such "introduction" and "replacement" effects emphasized the critical importance of providing a structured transition in the form of orientation and training regimens for both novitiate and established team participants to minimize potentially disruptive effects of altering the interpersonal and social dynamics of a microsociety.

The development of the Team Multiple Task Performance Battery (TMTPB) opened an important dimension to the research program. By imposing task requirements involving coordinated responses among team members, the analysis of the dynamic interplay between individual and team performance effectiveness was initiated within the context of ongoing "replacement" investigations. For example, it was found that the replacement of an established team member by a novitiate participant resulted in degraded performance on the individual subtasks of the TMTPB and in a shift in the operation of the team subtask itself. These findings suggest that a novitiate's lack of experience and skill on critical aspects of a task requiring coordination could be masked by experienced team participants who were perhaps unwilling to tolerate even a temporary degradation in overall team performance effectiveness. By developing methods to detect and quantify the relative contributions of individual members to the operation of the team task, intervention guidelines or pre-training schedules could be investigated that would ensure the most effective balance between individual and team performance effectiveness and subtask competency under the various conditions of membership turnover.

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