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ISSUES IN DEVELOPMENT, EVALUATION AND USE OF THE NASA PREFLIGHT ADAPTATION TRAINER (PAT)

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INTRODUCTION

The Preflight Adaptation Trainer (PAT), presently under development by NASA and its contractors, addresses the reduction or alleviation of space adaptation syndrome or, less euphemistically, space-motion sickness (SMS). SMS is believed to result primarily from sensory rearrangement, the altered relationships among sources of sensory information that are characteristic of microgravity environments. Adaptation to these novel sensory conditions seems to occur in most space travellers within a few days; prior to that time, however, SMS can disrupt normal performance patterns and impact mission efficiency. The broad objective of the various modes of the PAT development is to provide opportunities for portions of that adaptation to occur under normal gravity conditions prior to space flight.

The use of such approaches is a novel concept. Other than some limited (and not entirely satisfactory) experience with vertigo trainers, there is little or no precedent to guide the development and application of earth-based trainers toward achieving the desired effects on SMS and performance in actual orbital flight. Likewise, there is only limited information on evaluation of the trainers to determine if those desired effects have been produced. There are three main areas of activity in PAT development and use that are particularly important to success of the program. These involve: a) defining the specific <u>training objectives</u> to be accomplished by each trainer configuration, b) specifying the <u>evaluation criteria</u> and evaluation mechanisms for examining post-trainer effects, and c) describing the <u>training procedures</u>, protocols and supplementary materials required to conduct the actual training.

The purpose of this document is to identify and discuss the major technical issues and key decisions associated with each of these classes of activity. It will draw on the general literature in learning, training and education and on lessons learned from simulation and training efforts in other domains. Much of the relevant literature on adaptation and sensory rearrangement is brought together in the PAT Science Plan (Parker & Welch, 1987) and will not be duplicated here. This report is structured as a supplement to that document, with particular emphasis on the <u>demonstration and training</u> uses of the PAT configurations. Each of the next three sections focuses on one of the three major classes of issues and decisions defined above, i.e., what are the training objectives, what procedures should be used to address those objectives, and how can we tell if the objectives were attained.

SECTION 2.0

ISSUES IN DEFINING TRAINING OBJECTIVES

The stated overall objectives of the PAT (Parker & Welch, 1987) are fourfold: a) Demonstrate the sensory phenomena of microgravity; b) allow for task training in altered sensory environments; c) modify sensorimotor reflexes; and d) reduce or eliminate SMS symptoms. While these are appropriate as desired outcomes in a global sense, they are not sufficiently specific for a training system development. It is necessary to go a level of indenture below these overall statements to derive more detailed training objectives. These objectives can in turn be used to generate procedures and material for training, and serve as statements against which trainer effectiveness can be directly evaluated. Clear objectives are important because they can dictate in a very straightforward way how the training system will be used, and indeed provide an opportunity for developers to make sure that a trainer or training device is embedded in a context that makes it a training "system."

A training objective is a statement of the expected change in the knowledge base or skill repertoire of a trainee as a result of training. A "good" training objective will in general specify a desired outcome for a training process, defined in terms of a skill or knowledge which the trainee will possess at the conclusion of training. Ideally, a training objective will also describe the extent to which the skill or knowledge should be mastered, and the action by which that mastery will be demonstrated. For example, "...the student should know the procedure for management of an engine fire warning. The procedure must be successfully performed two consecutive times in the simulator and once in the aircraft."

The purposes underlying PAT development differ to a considerable extent from those of a conventional training system development. The adaptation aspects of the PAT objectives involve modification not only of the "behavior" of the trainee, but also of the sensory receiving and processing and motor output systems underlying the generation of behavior, an element of trainer use much less well understood than the more directly observable outputs or performances normally available as an index of what has been learned. In other words, the absence or presence and extent of adaptation can not be directly verified through behavior or observation; it can only be inferred. In that respect, the PAT requires unusually careful attention to the <u>specification of expected change</u> in the trainee and the means of verifying that the change has taken place. To understand the need for that attention, it is necessary to examine in greater depth some of the ways in which a trainee can be affected by exposure to a training system.

2.1 Mechanisms for Improving Performance in Microgravity

There are essentially four mechanisms by which a PAT-centered training system can bring about changes in an individual's capability to perform under conditions of sensory rearrangement. All of these can be thought of as forms of "training." The first three, familiarization, demonstration and training, are directed toward modifying the crewmember's "behavior" without modifying the crewmember, and are likely to be present in any well-designed training system. The fourth, adaptation, is directed, at least theoretically, toward some more-or-less permanent modification of the individual's sensory apparatus, and is in a different domain than the usual training approaches, which are oriented toward the provision of "knowledges and skills." In making decisions about what the PAT is intended to do and how it should be used, it is important to deal separately with the objectives of these four mechanisms, since they may require different procedures and training protocols for satisfactory implementation. The nature of each mechanism and its relevance to reducing the operational impact of SMS are discussed below.

2.1.1 Familiarization

Possibly the simplest level at which the problem of SMS can be addressed is to provide detailed information to each potential crewmember about the sensory rearrangement phenomenon. In education terminology, this comprises the passing of "knowledges" or factual information, either as an objective in itself or as a basis for later, more active demonstration or training. With respect to SMS, the procedure would involve detailed technical instruction about the physiological underpinnings of sensory rearrangement, the process by which the phenomenon occurs in microgravity environments, the likely perceptual and behavioral effects, the impact on performance, and ways in which the effects can be minimized or controlled.

Familiarization does not change the organism or provide any new skills. Rather, the purpose or "objective" of such instruction is to provide some understanding of the processes involved and to improve performance by reducing anxiety or disruption should SMS develop during flight. Further, such technical information will increase the benefit from later procedures which provide more in-depth experience with the phenomenon. Typical training objectives at this level might be: 1) "The crewmember shall understand the role of the vestibular system in maintaining orientation and equilibrium in normal gravity environments." 2) "The crewmember shall understand the interactions of the vestibular system with visual inputs and their effects in normal gravity." 3) "The crewmember shall understand the changes which occur to the vestibular system in microgravity and their expected effects on perception and orientation." Along with each objective could be a statement indicating how the development of "understanding" will be monitored, e.g., a test score of some value. Given the quality and motivation of potential crewmembers, however, it is not likely that testing would add materially to the benefits of familiarization.

The familiarization process can be conducted whether or not the PAT is available, and is likely to be of value by itself, but is also an important first step in the training process. In military aviation, for example, demonstration and use of life support and escape equipment is preceded by a series of formal, syllabus-guided "familiarization" lectures on the physiology of low pressure and high-G environments and the effects of these environments on humans.

2.1.2 Demonstration

Demonstration, like familiarization, is aimed at fostering an understanding of the effects of altered sensory relationships, rather than any deliberate modification of the perceptual apparatus. As a training technique, it goes beyond technical instruction in providing an opportunity to view or experience the phenomenon directly. Demonstration, however, remains a passive technique. The trainee is a "passenger" with little or no control of his environment nor any assigned tasks to perform.

The benefits of demonstration are much like those of familiarization in that they reduce "surprises" in orbital flight, but are likely to yield greater insight into the phenomenon than instructional orientation alone. Likewise, the training objectives for demonstration are much like those for familiarization except that they emphasize recognition of altered sensory relationships, rather than understanding or knowledge, i.e., "The crewmember shall be able to recognize the presence of visuo/vestibular conflict and identify its expected effects on perception of orientation." There is no straightforward way to verify the occurrence of the desired effects of demonstration other than self-report.

The various PAT modes are an ideal vehicle for demonstration, most beneficially as a follow-on to formal instruction and as a precursor to the programmed exposures required for adaptation and training. It is quite possible, however, that familiarization and demonstration alone may be sufficient to attain most of the insight required by the crewmember to minimize the inflight effects of rearrangement. Demonstration as an approach to management of unusual conditions and environments has a long history in aviation training. Low-pressure chambers are used to demonstrate the symptoms surrounding the onset of hypoxia. Disorientation simulators show the extent to which loss of the visual horizon induces confusion in perceived aircraft attitude and orientation. The Navy's well-known "Dilbert Dunker," although it involves some active participation by the trainee, is largely a demonstration device to reinforce the importance of following exact procedures in escaping from a submerged inverted aircraft.

2.1.3 Training

Training implies an active modification of the behavior of a trainee by some deliberate intervention, designed to encourage the development of certain specific skills. The set of skills which the crewmember will have after training that were not present before training define the objectives of training, and these objectives in turn govern the procedures to be used in fostering skill development.

Training differs from familiarization and demonstration in the requirement for active and direct participation by the trainee in the process; the trainee is required to react to the environment and to produce responses appropriate to the ongoing flow of activity. It resembles those simpler processes, however, in that it is aimed directly at changing the behavior of the trainee in specific environments, that is, the learning of new responses to the perceptual cues present in those environments. It thus differs from adaptation, which focuses on changing the "internal wiring" of the trainee, i.e., creating a new set of "percepts" arising from translation or reinterpretation of perceptual information. Adaptation in a sense changes the "filters" applied to sensory and proprioceptive information to provide a modified view of reality, while training teaches the individual to generate new response sets to information for which the perception is unchanged. In reality, the two concepts are not as different as they appear; we will revisit these ideas in later discussions of adaptation.

2.1.3.1 Coping Strategies

In the context of orbital flight and the simulation of that environment provided by the PAT, training (as distinct from adaptation) offers several avenues to reduce the impact of sensory rearrangement on mission performance. Most important of these is the emergence through training of "coping strategies." Coping strategies serve in effect as "add-ons" to existing behavioral response repertoires. They do not replace previously learned response sets, but rather serve as emergency response programs that can be invoked under special circumstances for which the usual responses are inappropriate or even hazardous. Coping strategies override routine procedures, are normally in force only for relatively short periods, and are generally triggered by specific situational or contextual cues. These cues must themselves be learned, and are internalized from demonstration followed by practice in a structured training situation. Note that demonstration alone may be sufficient to introduce and teach coping strategies, particularly when they are simple and intuitive, i.e., restricting head movements, aligning with the axis of acceleration, etc. There are other forms of coping strategies unrelated to the trainer (biofeedback, self-hypnosis, etc.), but we are not concerned with them here.

We described above the role of the disorientation trainer in demonstrating the difficulties encountered by a pilot in managing aircraft attitude in the absence of a visual horizon. The coping strategy for disorientation is simple -- pilots are taught to "...get your head back in the cockpit," i.e., use the instruments to regain orientation. The cue for invoking this simple coping strategy is any discordance between perceived attitude or acceleration and the attitudinal gyro or the rate of climb indicator.

Similar coping strategies can be identified for the numerous discordances among sensory inputs likely to be encountered in orbital flight. The PAT provides a dual capability for this purpose, i.e., it can be used both to study a phenomenon and to train crewmembers in managing the effects of that phenomenon. To obtain the most effective use of the PAT in preparation for space flight, some preliminary studies of potentially useful coping strategies are likely to be required. The studies should: a) identify effective strategies for management of sensory conflict, b) determine the cues which should trigger these strategies and c) develop training procedures which teach and reinforce those cues. The "training objectives" for coping strategies should be in part an extension of those for demonstration. That is, for each specific condition of sensory conflict, there should be an objective with a statement about recognizing that particular conflict, isolating the appropriate cues and identifying the appropriate strategy, and performing the correct coping behavior.

2.1.3.2 Practicing Mission Tasks under Altered Conditions

The development of appropriate coping strategies is one of two major benefits from carefully structured training procedures on the PAT system. The second opportunity for improved operational performance involves the opportunity to practice mission-relevant tasks under the altered perceptual conditions of microgravity. A truism of training programs is that when the conditions of task performance are significantly changed, it may be necessary for an operator to develop significantly different procedures for task performance, even when the task itself remains unchanged. This modification of procedures is particularly critical when the task procedures are highly practiced and are approaching what is sometimes called "automaticity."

2.1.3.2.1 Automaticity

When an individual is first introduced to a task (particularly a complex one), performance of the component procedures is not well coordinated and considerable attentional effort is required, that is, extensive voluntary control must be exercised. As practice continues, the attention demanded is progressively reduced, and the processes for task management assume the status of involuntary mechanisms. Such tasks are said to have transitioned to a state of automaticity (Shiffrin & Schneider, 1977). Once initiated, automatic tasks proceed with minimal expenditure of attentional resources other than to monitor the effects of outputs on task performance. While the semi-voluntary control of such highly practiced tasks frees time and attention for use in other job or mission activities, the mechanisms for control are so ingrained in the individual that they are very resistant to modification or to "unlearning." They thus may continue directing task performance even in different environments or under new conditions for which they may not be totally appropriate. The overlearning associated with automaticity commonly results in "negative transfer" of learning to a similar but not identical task (Cormier, 1984; Lane, 1987).

2.1.3.2.2 Distinctions between Negative Transfer and Incomplete Adaptation

The "negative transfer" from prior overlearning is distinct from an additional use of the term to refer to the potential for incomplete or inappropriate adaptation resulting from inadequate or imperfect representation of weightlessness conditions within the simulator. In the first usage, the concern is with interference in performance of task A_2 arising largely from procedural confusion with task A_1, that is, the same cues may demand different responses in A_2 than in A_1. In the latter usage of the term, the concern is rather that the perceptual cues provided by the simulation may themselves be incomplete or only partially incorrect, and that adaptation, the process by which altered sensory input is automatically translated by the perceptual apparatus and linked to appropriate responses, may be likewise incomplete or only partly correct.

The "procedural confusion" or interference problem is somewhat more manageable than that of incomplete adaptation, and is addressed in the next section. If the trainer is providing cues that are incomplete or inappropriate for the desired adaptation effects, and if adaptation occurs, and if adaptation is necessary for successfully overcoming early SMS, then the lack of fidelity to the microgravity environment could be a serious problem, threatening not only the adaptation objectives of the PAT, but also the demonstration and training objectives, since these also require some degree of cue fidelity in order to be effective.

There is probably no straightforward way to guard against insufficient cue fidelity. The PAT design will represent the microgravity cue environment as closely as the state-of-the-art in simulation will allow, and attempts to increase fidelity are not likely to yield materially better results. There are, however, several factors which operate to minimize the risk to PAT success of an imperfect simulation. First, we have noted earlier that the occurrence of adaptation may not be necessary for the PAT to be effective in management of SMS; familiarization and demonstration alone are likely to be sufficient to ameliorate, although not eliminate, the SMS problem. Second, once the phenomenon of sensory conflict is introduced and explained, and a demonstration given, there is a heightened sensitivity on the part of the crewmember toward the likelihood of sensory rearrangement as such, and an awareness of the need to deal with the effects of the phenomenon. Whether the cue complexes in the trainer are of perfect fidelity may be less important than that awareness. Third, while no convenient index of "perceptual fidelity" is available, it is not probable, given the careful developmental history of the PAT, that the sensory cues provided will diverge dramatically from those of microgravity. In particular, while the cues may be in part "incomplete," they are unlikely to be misleading, i.e., to point to inappropriate actions. Thus, while transfer of adaptation may be less than total, it will almost certainly be positive rather than negative.

2.1.3.2.3 Reducing Interference and Negative Transfer

Because it is so difficult to modify well-learned tasks, it is often more effective to teach a new set of procedures (or allow the individual or team to develop one) that is keyed to the cues present in the new environment. These new procedures may be very much like the old ones, but because they are invoked by different cues, are not as likely to produce interference or negative transfer as attempts to modify the previous ones. The new cues may be of many different types. In the altered environment of spaceflight, the important cues are likely to be sensory and perceptual rather than procedural, i.e., the recognition of sensory arrangement may itself be the cue which causes a new set of task procedures to overlay those learned under conventional perceptual conditions. The critical objectives of training are thus to demonstrate the cues, and to provide task practice which allows modified task procedures to be developed and become "learned," that is, systematically associated with the new cues. These new procedures can thus serve as "overlays" that are triggered by the new cues and replace the ways of performing that are inappropriate in the new environment, thus reducing the risks of interference from previously learned procedures.

An example of such procedural modification can be seen in the re-training required for operators and maintainers performing their normal tasks while wearing chemical defense protective equipment (Lane, 1983). This equipment includes a heavy suit which impedes movement, a hood and mask which restricts vision, and heavy gloves which make manipulation awkward. The well-learned sequences of task performance seen in highly trained operators are virtually impossible under such conditions, and tasks which require teamwork among several operators (refueling, loading equipment, etc.) are even more seriously disrupted. With sustained practice in protective equipment, however, a new set of procedures will emerge which restore much of the previous proficiency.

Similarly, astronauts performing (for example) maintenance or assembly tasks in space wearing pressure suits face a related problem. An assembly task in a pressure suit is, from the standpoint of the astronaut, a different task than the same procedures without the constraints of the suit, and still a third task when assembly is performed in a suit under conditions of microgravity. Add the additional and unusual muscular exertion required to offset glove pressure (Schmitt & Reid, 1985), and the tasks diverge even more.

For both of the above examples, it is important to recognize that the <u>task</u> to be performed is apparently unchanged, and that the <u>procedures</u> for performing will not appear dramatically different from prior ones, except in the timing and sequencing. The <u>cues</u> which trigger the procedures, however, may be quite unlike previous ones, and may involve the continuous "feel" or awareness of wearing equipment which defines the new task environment. Thus, to an operator, unprotected and protected task performance simply becomes two different tasks, each with its own independent cues and procedures. To reduce interference and confusion of procedures, training for maintaining performance under sensory rearrangement during space flight should follow a similar process.

2.1.4 Adaptation

2.1.4.1 Distinctions between Adaptation and Training

It was noted earlier that training involves the learning of new cues and procedures in response to altered sensory and perceptual information, while adaptation involves some degree of transient or long-term adjustments of the sensory and perceptual apparatus, translating sensory information such that altered sensory input is linked to previously learned cues and procedures. It was also noted that familiarization, demonstration and training can be seen as succcessively more active ways of fostering the development of new skills and strategies for use in space flight, while adaptation (in the sense of sensory changes) lies in a different domain and could be facilitated by both demonstration and training. Training and adaptation are thus conceptually distinct mechanisms, but both are likely to affect behavior and performance in the same way in the target environment, and the effects of the two mechanisms may in practice be hard to distinguish. Indeed, it is difficult to imagine a realistic situation for training under sensory rearrangement that did not contribute in some way to adaptation.

Training and adaptation are treated separately here because they may have different implications for trainer design and use, deriving largely from the contrasts drawn above -- training for new conditions explicitly requires both exposure to the condition and concurrent practice, while adaptation in theory requires only exposure to altered conditions for the desired effects to occur. It is thus possible to develop a variety of paradigms for PAT use that differ along several axes. a) To what degree is the nature and intensity of the exposure profile varied? b) Is the profile controlled by the trainee or the instructor? c) Is the same profile presented to each trainee? d) Is a task performed concurrently with exposure? It may be that a concurrent task can accelerate or retard adaptation. e) Is the task representative of a mission task? f) What is the likelihood of negative transfer/interference? These questions are important for decisions about PAT application and will be expanded later.

2.1.4.2 What Do We Mean By Adaptation?

An even more critical question for addressing the role of adaptation in PAT use is a more precise understanding of what is meant by the "adaptation" label of the Preflight Adaptation Trainer. It is our belief that the concepts of adaptation as described in the PAT Science Plan (Parker & Welch, 1987) are virtually coincident with the usual conceptualizations of "perceptual learning" from the learning/training domain (e.g., Gibson, 1969). Gibson describes perceptual learning as an increase in the ability of an individual to extract information from a stimulus in an environment as a result of experience or practice in that particular environment. This is equivalent to the formation of a set of filters to be applied to the sensory and proprioceptive information available in the environment. These filters deal with the "credibility" of different information sources (visual, vestibular, tactile, kinesthetic, etc.), and are derived from active, continuing interaction with the environment and the resultant feedback. They thus serve as weights for the different sources in integrating available sensory evidence to arrive at an interpretation of reality.

2.1.4.2.1 Adaptation vs. Perceptual Learning

So long as the feedback provided by the environment remains constant, these filter sets are effective in providing correct cues for guiding performance. When sensory relationships are decorrelated, however, these filters are inappropriate for resolving conflicts among environmental information, and new ones must be formed which reflect the credibilities of sources in the new environment. These new sets are likely to be created in much the same way as the original ones were, that is, by "trial and error" reality testing in the new environment. Based on the outcome of that testing, higher weights are attached to some sensory information and lower weights to others depending on the credibility or utility in the altered setting. This process of "sensory compensation" is functionally equivalent to most conceptualizations of the process of "perceptual learning," in that discordant stimulation is inhibited or suppressed, and reliable or "invariant" cues are detected and reinforced.

It has long been known that transfer of motor learning involves considerable task and context specificity (Cormier, 1984). Similar specificity appears to be the case in vestibular adaptation (Berbaum, Kennedy & Welch, 1986). True "classic" perceptual learning (e.g., size constancy, sight pictures) may have much broader stimulus generalization than either motor or vestibular. For example: a) after adaptation to SMS, astronauts have markedly increased resistance to other forms of motion sickness (Graybiel, Miller & Homick, 1974); b) the adaptation to Coriolis Purkinje conveys savings to pseudo-Coriolis (Kennedy, Berbaum, Williams, Brannan & Welch, 1987).

As the above discussions suggest, distinctions between adaptation (particularly sensory compensation aspects) and perceptual learning are by no means straightforward. Much of what Gibson (1969) considers as perceptual learning is summarized by Welch (1986) as part of adaptation. There is a lack of consensus among authorities on such key issues as the relative durations of effects for learning vs. those for adaptation and the extent and nature of neural involvement in the resultant changes in behavior. For purposes of this document (and for training), both processes act to resolve discordance in the same way, by forming new associations between stimuli and the responses to those stimuli, and can be treated effectively as the same concept. A key role of the PAT is thus to provide an environment which fosters those associations, and it might be considered as much Preflight "Association" Trainer as one for "Adaptation."

The concept of associations formed by an altered stimulus and a derived response is likewise important to the other form of adaptation identified in the PAT Science Plan (Parker &

Welch, 1987), that of "sensory reinterpretation." Under microgravity, vestibular and other graviceptor information used to determine tilt under earth gravity is reinterpreted to provide information about linear motion. This is a direct reinterpretation, probably by the cerebellum or tectum, rather than the inhibition/augmentation process characteristic of sensory compensation (or perceptual learning). It is likely, however, regardless of the neural location of the adaptation, that its development will follow the same mechanisms as compensation and perceptual learning, that is, exploratory behavior in a new environment with resulting feedback and the formation of associations between sensory inputs and response outputs that promote appropriate orientation and movement in that environment. Thus from the standpoint of demonstration and training, sensory reinterpretation need not be treated as a separate concept, although it may be necessary to deal with it in a different way during evaluation.

2.1.5 Summary

All the mechanisms described above, familiarization, demonstration, training and adaptation, are directed toward improving performance during space flight by providing crewmembers with information about or practice in an altered environment. The first three form a logical sequence of orientation and training stages which promote learning to perform relevant tasks in the altered environment and should contribute to more rapid adaptation to microgravity conditions.

Each mechanism or stage, however, has specific objectives that need to be described in order to get best use of the PAT systems. These objectives are important for two major purposes: a) They serve as anchors for evaluation (have the desired effects taken place?) and b) they drive the content and organization of training procedures, manuals, and other documentation, and help to define the roles of PAT instructors and operators.

SECTION 3.0

ISSUES IN PAT EVALUATION

Evaluation of the effectiveness of PAT training is concerned with the third of three general questions about the trainer and its use. 1) What is the human like going into the PAT? This deals with entry level characteristics, an implied precursor to defining training objectives. 2) What do we want him or her to be like when training is finished? These are the training objectives. 3) How can we tell if the training accomplished its purposes? These involve the "metrics of success," the indicators of change, and should relate as closely as possible to the training objectives. The general approach to evaluation of the PAT is much like that for examining the effects of any procedure or intervention intended to change human capabilities or performance, and is reflected in the seven general steps below:

3.1 A General Approach

a) Define the purposes of the proposed training in clear terms that are susceptible to testing at the desired level of formality.

b) Define the specific behaviors, performances and other observable indicants associated with the purposes of training. These should ideally be in quantifiable metrics, but may also involve subjective or self-report information.

c) Define the initial status of trainees on these behaviors and observables.

d) Define the desired direction and/or amount of desired shift on each metric.

e) Provide orientation, demonstration and other training interventions appropriate to the objectives of training.

f) Compare initial to post-training status on the "metrics of success."

g) If appropriate, conduct follow-up evaluation, examining transfer, retention and other "savings" from the training procedures.

While this approach is unrealistically formalized and somewhat oversimplified for a program of the novelty and complexity of PAT, it highlights some essential steps in determining if PAT accomplishes its intended purposes. In particular, specifying the metrics of evaluation in observable terms, along with the operations by which those observables will be quantified or measured, is the key to a conclusive evaluation of PAT effectiveness. There are several criteria that should be considered in selecting the measures by which effectiveness will be judged, because the properties of the chosen measures can have a major effect on evaluation outcomes independent of the presence or absence of any training benefits. The most important of these are discussed below.

3.2 Selecting the Measures of Training Success

3.2.1 Desirable Properties for Measures

In developing a plan for training evaluation, it is not always well understood that the choice of measures on which evaluation will be conducted can "make or break" the results of an evaluation. The psychometric properties and the content of the measures selected have an inordinate influence on the degree to which training effectiveness can be demonstrated. There are a number of attributes on which evaluation measures can be judged as potential indices of effectiveness. Lane (1986) identifies seven such "criteria for criteria" involved in the choice of evaluation metrics. Although each of these criteria is important in measure selection, there are, for purposes of PAT evaluation, three measure properties that are most critical -- reliability, sensitivity, and relevance.

3.2.1.1 Reliability

Although there are a number of different ways in which reliability of a measure can be determined, the most useful conceptualization for purposes of evaluation is that reliability indicates the extent to which successive measures of the same variable obtained under the same conditions will yield the same outcomes. Reliability thus defined is called "test-retest" reliability, and relates to the stability of the behavior or performance or attribute being measured. If, for example, individuals show major shifts across time in task performance or in a physiological measure, the portion of the measure due to "error" will be large, and it will be nearly impossible to detect the effect of training or other interventions.

Low reliability can occur for many reasons. The phenomenon itself may be inherently unstable from one time to another; blood pressures, for example, are notoriously labile. Measures may be affected by uncontrolled variables (diet, sleep loss, circadian rhythms, motivation, etc.). Individual differences among people may be so large as to overshadow other regularities in the measures. On a task performance measure, individual performances may be unstable in that practice is still occurring; conversely, everyone in a group may be so well practiced that the task is very easy and there is little variance within the group, lowering reliability values.

Note that reliability as defined above has little to do with the properties of the measuring instruments or apparatus. The "precision" of measurement or lack thereof, what Lane (1986) calls "properties of the yardstick," has only moderate effects on test-retest reliability. A yardstick that is inaccurate or imprecise, but consistently so, will tend to yield acceptably reliable measures.

The usual finding of evaluations with unreliable measures is one of "no differences," since a variable which does not relate to itself in successive measurements cannot be shown to be systematically related to any other variable of interest. To make sure that an evaluation yields a definitive outcome, pro or con, reliability of measurement is the single most important attribute, since without adequate repeatability of assessments, no other attributes matter.

3.2.1.2 Sensitivity

Sensitivity reflects the extent to which a measure can be expected to change in a lawful way, i.e., in accordance with and in proportion to some intervention (such as training) which should change an individual's status on that measure. When, through training or adaptation, we change an individual's capability to perform a task or modify some aspect of his or her perceptual functioning, a sensitive measure will show a shift concomitant with the amount or degree of training or modification. A measure can be insensitive because it is unreliable, or because the bringing about of the desired change requires too intense an intervention (too much training or adaptation) to be practical within a normal paradigm. Similarly, a task that is too easy or too difficult for the group being measured will be insensitive, since a highly-practiced task is difficult to disrupt or modify, and a very difficult task will have a restricted range of scores. Reliability and sensitivity are intricately related; an unreliable measure cannot be sensitive, although an insensitive measure for one purpose may in fact be acceptably reliable and sensitive for another purpose.

3.2.1.3 Relevance

A measure is relevant to evaluation if a trainee's status on that measure can reasonably be expected to change as a direct result of training or induced adaptation. Relevance thus requires an explicit linkage between the intervention and the expected value of the measure before and after intervention occurs. The linkage can be direct or indirect, but should be consonant with theoretical expectations, i.e., there should be a plausible reason for examining change on a given measure, and the direction of change should be predictable from those expectations. Shoe size, for example, although likely very reliable, would be an inappropriate evaluation measure on that basis. Attention to relevance serves as a protection against a common deficiency in measure selection, the tendency to evaluate too many measures, the so-called "if it moves, measure it" syndrome. Too large a measure set, with insufficient rationale for measure inclusion, can lead to an overcapitalization on chance effects, particularly when the sample size is small or, as is likely in training astronauts, inherently restricted in number relative to the size of the possible measure set.

3.2.2 Classes of Measures

When we set out to evaluate training effectiveness, we are in essence looking for evidence that indicates whether or not training has had an effect and what the nature of that effect might be. That evidence can span a variety of different measurement domains, that is, there are many different kinds of evidence which can provide clues about training effects. The available classes of measures vary along several dimensions -- the degree of objectivity/subjectivity, the extent to which measures tap directly into performance dimensions rather than theoretical correlates of performance, the ease and practicality of data collection, and so forth. There are five broad classes of evidence that may bear on training effectiveness. Each has its advantages and disadvantages. These are outlined below.

3.2.2.1 Performance in orbital flight

Since the ultimate objective of the PAT is to reduce the impact of SMS on operational performance, the most powerful evidence on effectiveness would be direct measures of inflight performance. This is likely to be impractical for many reasons. First, we do not know exactly which ones of the many different tasks to measure, nor usually how to measure them reliably (see Lane, 1986, concerning reliability problems with operational measures). Secondly, the process of measurement could easily interfere with mission performance. Third, the ideal study would compare the performance of the same astronaut on the same flight with and without PAT exposure (a logical absurdity). Lacking such a "control" group, direct measures of performance, despite their appealing relevance, would provide only limited evidence of adaptation or training effects.

3.2.2.2 Performance of mission tasks in the trainer

A close second in relevance to inflight measurement is the assessment of performance on selected mission tasks in the PAT itself. Although the environment is only an approximation of orbital flight with respect to sensory rearrangement, it is a more friendly one for controlled data collection and for task practice.

3.2.2.2.1 Practice tasks vs. Assessment tasks

It is important to make distinctions in task selection between those tasks performed in the trainer to train or to facilitate adaptation, and those performed for purposes of assessment or evaluation. These need not necessarily be, and for some evaluation paradigms, should not be, the same tasks. An important benefit of the PAT is the opportunity for crewmembers to practice mission-related tasks under conditions of sensory rearrangement, that is, tasks which are similar to, if not identical to, those performed inflight. As noted previously, such practice provides advanced demonstration and training, and aids in the development of adaptation. Some of the tasks which might be most useful for demonstration, training and adaptation, however, may not be "good" tasks from a measurement or evaluation standpoint, i.e., they may not yield measures with the desired metric properties. Task selection should reflect these differences in purpose.

Three classes of mission-related tasks have been proposed for the PAT: a) Self-motion involving control of body orientation under rearrangement (e.g., acrobatics); b) locomotion (purposeful movement from place to place under rearrangement); and c) simple procedural tasks (read displays, push buttons, etc.). Each of these is a reasonable analog of tasks in an orbital mission, and can reasonably be expected to generalize to inflight tasks, that is, practice on the PAT tasks should provide transfer or adaptation savings to other tasks under actual mission conditions. Such projections of transfer and savings can be derived from a broad literature base concerned with transfer between tasks with common elements, and from a less-extensive but no less compelling base of knowledge about sensory adaptation. Restated, there are sound scientific reasons to expect positive effects from PAT training, with little downside risk of adverse effects.

The purpose of a formal evaluation, however, is to estimate explicitly the likely benefits through a series of studies designed specifically to examine transfer/adaptation savings. Within that realm, the distinction between tasks performed for practice and tasks performed for measurement of performance becomes significant. Of the three classes of PAT task activity (self-motion, locomotion and procedural): 1) Self-motion and other "free-play" activities may be difficult to score objectively and reliably. 2) Locomotion may be scoreable with respect to, for example, time to traverse a specified route, so long as the tasks and the trainer are designed for that purpose, and improvements across time can provide indications of change with practice. Locomotion tasks such as movement through confined spaces (tunnels, etc.) could incorporate specific waypoints (e.g., strategically located buttons to press) that could be automatically recorded and processed to yield elapsed and total time measures. 3) Procedural tasks (read dials, press buttons) present some difficulty within an evaluation framework. To the extent that they mirror actual inflight tasks, they tend to require special equipment, special software, are only appropriate with fully-trained crewmembers, and do not always lend themselves to reliable scoring. To the extent that tasks are "novel," i.e, simplified analogs distinct from but with elements in common with actual tasks, there tend to be distinct learning curves which may require extended practice to "flatten out" and are thus not always suitable as evaluation tasks, although they may be perfectly satisfactory as practice tasks within the altered sensory environment.

3.2.2.2.2 Probe tasks

The distinction between tasks for practice and tasks for measurement/evaluation purposes leads to a further distinction, between tasks performed routinely during trainer sessions and those given on some less frequent schedule to assess transfer or adaptation, what might be called "probe" tasks. Probe tasks are not practiced under active trainer conditions other than when performed for measurement purposes. They are, however, practiced outside the trainer, or in the trainer without sensory rearrangement, until the practice curve has flattened out, and are thereafter administered only in accordance with a preestablished schedule (every third practice session, etc.).

The probe task should, like practice tasks, have elements in common with inflight tasks, but should not be identical to any of the practice tasks. The purpose of a probe task is to determine the generalizability to other tasks of any transfer or adaptation effects that may be occurring as a result of trainer exposure, in particular the changes in probe performance as a function of cumulative exposure time. To use a probe task paradigm for evaluation, it may be desirable to withhold otherwise suitable practice tasks (e.g., procedural tasks) to serve as a probe. By providing different crewmembers with differing profiles and sequencing to different PAT modes, it may be possible with a probe paradigm to acquire comparative evidence of PAT effectiveness for different modes and schedules. This may require extended experimentation, and can be too complicated for use with astronaut populations; some of these studies, however, could be carried out effectively on non-astronaut subjects.

A further difficulty with probe task paradigms is that it may be difficult to identify practice and probe tasks that fit the above constraints and are sufficiently distinct to serve as dependent variables in the designs required by the practice/probe approach. In addition, such tasks may require considerable practice for non-astronaut groups to become sufficiently proficient for performances to be compared across time, and historically tend toward reliability problems (Lane, 1986).

3.2.2.3 Performance of surrogate tasks in the trainer

A more practical paradigm is to use the evaluation approach above, replacing the probe tasks with one or more "surrogate" tasks. In the surrogate approach (Lane, Kennedy & Jones, 1986; Kennedy, Lane & Kuntz, 1987), measures which tap skills related to mission-related tasks, but with better metric properties, are substituted for those more directly relevant tasks. Surrogate tasks typically have much higher reliabilities than operational tasks, require considerably less practice for performance to stabilize, and need less testing time to yield equivalent amounts of information. While surrogate tasks have less "face" relevance, their improved metric properties can in reality provide a more powerful test of effects than can operational or directly mission-specific tasks. From the standpoint of objective evaluation of trainer effectiveness, the surrogate approach is likely to be both more practical and more powerful than either direct inflight or trainer measurement of mission tasks.

An appropriate surrogate set for PAT evaluation is the Automated Performance Test System (APTS) developed for NASA and the National Science Foundation (Essex Corporation, 1988). The APTS is a battery of (currently) more than 30 cognitive and motor tests, selected for properties of high reliability, rapid stabilization with limited practice, and demonstrated sensitivity to a variety of stressor conditions. A major purpose underlying APTS development was to provide a standardized method to study SMS effects in orbital flight, and the battery would be equally suitable for that purpose or for evaluating adaptation in the trainer.

3.2.2.4 Anecdotal or self-report information about symptoms

Next to the precise (but difficult) measurement of orbital performance, there is probably no more direct evidence of trainer effectiveness than the insights of crewmembers during exposure to microgravity. The subjective "feelings" of individuals about the effects of sensory rearrangement, and the extent to which PAT exposure has ameliorated those effects, are parallel to and as valuable a source of information as the more objective experimentation described above. It is important, however, that such information be obtained in an organized and systematic way.

Beyond the free-form anecdotal data (as in Schmitt and Reid, 1985), which is useful but difficult to analyze, there should be some standardized method for collection of inflight SMS symptomatology which quantifies both the nature and extent of symptoms. Several such approaches should be considered. A technique developed by Herbert Simon called Protocol Analysis offers considerable promise but has had limited use in measurement applications. In Protocol Analysis, the crewmember or trainee "talks through" a mission or an experience with a new phenomenon, describing cues, planned actions, feelings and other information which might be relevant to understanding the person's reactions and perceptions in that environment. Recorded utterances are then summarized through methods of content analysis. "Symptom checklist" methods should also be considered. In addition to the venerable but well-understood Pensacola Motion Sickness Questionnaire (MSQ) (Kennedy, Tolhurst & Graybiel, 1965) and its variants, there are some recent derivatives, in particularly the Simulator Sickness Questionnaire (SSQ) (Lane & Kennedy, 1988). The SSQ provides three subscales for symptomatology (Visuomotor, Nausea and Disorientation) and a Total Severity score, based on factor analyses of symptom responses. While the present format of the SSQ is specifically tailored to quantification of simulator sickness, the "symptom cluster" approach which it represents is highly diagnostic of the nature and probable physiological locus of experienced symptoms, and has been useful in several independent applications (Hettinger, Lane & Kennedy, 1988). Such an approach, in addition to providing metrically sound quantification of overall symptomatology, also yields subscale measures which can be of great value in focusing self-report information on areas in which PAT may have produced savings in adaptation, and would be useful both inflight and as an index of decreases in symptom severity during trainer exposures. Development of an SMS analog of the SSQ, based either on the MSQ/SSQ or the NASA SMS symptom database, is strongly recommended.

A further area of importance in self-report that relates directly to PAT effectiveness involves not the reduction or elimination of symptoms from sensory rearrangement but the perceived ability of crewmembers to manage or cope with symptoms when they occur. It was noted earlier that a key potential benefit of PAT was to foster the development of coping strategies to support continued performance despite the presence of otherwise disabling symptoms. Information on such perceived benefits should be collected in a systematic way similar to that for data on symptomatology. Either Protocol Analysis or a structured debrief supported by content analysis should be sufficient for self-report data collection and reduction.

3.2.2.5 Change in physiological and perceptual correlates

Because an important aspect of PAT development is to reduce impact of SMS on operational performance, the measure classes above tend to focus on direct measures of task performance or on direct perceptions of SMS symptoms. There are, however, a number of measures, distinct from those above, which are known or hypothesized to co-vary with adaptation and to serve as indices of its progression. Most such measures examine the observable results of what are presumed to be internal physiological or neural modifications. Among these are the vestibulo-ocular reflex (VOR) and associated changes in eye movements, shifts in illusory self-motion (vection), perception of the gravitational upright position, and changes in the size/distance relationship of objects. These correlates and their changes with adaptation are described at greater length in the PAT Science Plan (Parker & Welch, 1987), and will not be treated in detail here.

From a measurement standpoint, the significance of these measures is that they are correlates of adaptation, not direct measures of adaptation or of performance in task situations. Their value is rather that they are well-understood, relatively easy to obtain, and can probably be measured with greater reliability than most of the performance measures (specific provisions should however be made for determining their reliability during evaluation). Their disadvantage is that there is as yet no direct linkage between such correlates and task performance. The extent to which they provide direct evidence about adaptation as it affects performance is thus problematic. A valuable contribution of PAT evaluation would be to establish the presence or absence of links between these variables and some form of task performance.

3.3 Summary

The PAT Evaluation Plan must deal with several complicating realities. First, inflight measurement of performance may not be feasible, and it may be necessary to substitute one or more of several classes of measures obtained in the trainer itself. Second, the available sample of astronauts is likely to be too small for the detailed experimentation required to answer all the significant evaluation questions, and studies on non-astronaut populations may be necessary. Third, it is important to give equal weight in evaluation to objective measures and to subjective information and perceptions, and subjective data collection must be very carefully structured. Fourth, it is important during evaluation to establish logical links between the proposed physiological and perceptual correlates of performance and the performance itself. Spanning all these issues is the concern that the number of measures available to examine PAT effects will likely exceed those that can be properly studied with available sample sizes, and special attention will be required in selection of the candidate measure set.

SECTION 4.0

ISSUES IN PAT USE AND APPLICATION

Training hardware and equipment is only one leg of the four that support a good training system. The other three (in no particular order) are a) documented training procedures and materials that describe how the trainer will be used (sometimes called courseware), b) trained and knowledgeable instructors, and c) site preparation and equipment maintenance. The last of these will not be addressed here other than to emphasize its importance; even the best trainer and the most sophisticated training protocols are ineffective if the hardware is chronically off-line. Likewise there will be limited attention to the engineering characteristics of PAT hardware and software. The concern of this section is rather to highlight the issues and implications involved in using the PAT within a training system context, particularly those that have to do with instructional documentation and its application. In a earlier section we discussed the nature of training objectives and their importance for trainer development. Training procedures and protocols are the means by which those objectives are implemented in the training system.

Structurally, this section follows the sequencing of Section 2.0. We described three "training-related" mechanisms -- familiarization, demonstration, and training -- for fostering perceptual adaption and the learning of new task strategies appropriate to microgravity, and linked each of these to the fourth mechanism, adaptation. The following discussions expand on the instructional support requirements for each of the three mechanisms.

4.1 Familiarization

Familiarization with respect to PAT use would consist of a thorough grounding of crewmembers in the phenomenon of sensory arrangement, how it affects perception and behavior, and what to expect during orbital flight. This can be achieved in two ways -- lecture (classroom instruction) or self-study. In either case, instructional materials should be complete and provide an in-depth technical orientation, rather than a superficial overview. Obviously the principal difference between these approaches is the presence of an instructor in the classroom situation. We believe that the required familiarization can be accomplished through a carefully structured self-study program, using a workbook, a specialized textbook or a similar document prepared for that purpose. Such a document could also form the basis for more formal (classroom) instruction if desired. The instructional material should address the topics described in Section 2.1.1, and should contain, in addition to background on SMS and sensory rearrangement, guidelines for prevention of SMS or management of symptoms should they occur. Consideration should also be given in planning to the qualifications of the instructor(s) should such an approach be elected.

4.2 Demonstration

The principal goal of demonstration is to provide first-hand experience with simulation of the feelings and perceptual changes encountered in the altered environment. Although the trainee is largely passive (in most modes), demonstration has a powerful potential for furthering understanding of the rearrangement phenomenon beyond that possible with familiarization alone, in that it offers opportunity for exploratory movement and some practice with SMS management strategies. Because of this potential, however, demonstration should be conducted under explicit protocols which specify (among other information) the modes to be used, the number of exposures to each, time intervals between exposures, the intensities of stimulation to be given, for how long, and the degree to which feedback from the trainee is used to vary the "program" of stimulation.

Collectively, the series of protocols to be used define the "demonstration" aspect of the training procedures referred to so frequently in previous sections. They also determine to a large extent the role of the trainer operator or instructor, and the training and/or experience he or she should have to be effective. The importance of a skilled instructor/ operator in the success of the demonstration devices should not be overlooked. In addition to providing explanations and information to the trainee as the protocols are carried out (what reactions to expect, and so forth), the operator must watch for unusual reactions or other emergency situations and know the appropriate actions to take. Detailed guidance for demonstration use of the PAT devices should be spelled out in a document, essentially an "Instructor/Operator's Manual for PAT Demonstration." This may be a separate document or combined with similar information for carrying out training procedures (see below).

There are decisions to be made in deriving demonstration (and training) protocols that may have a significant bearing on the success and acceptance of the PAT program. These decisions concern the intensity of stimulation administered to a trainee and the extent to which protocols provide for tailoring intensity and exposure length to an individual trainee's threshold of susceptibility. It is likely that the devices can bring any trainee to the point of advanced motion sickness rather rapidly, and that a protocol which is easily tolerated by one trainee may induce major symptoms in another. Operating past individual thresholds may be counterproductive both from the standpoint of achieving best adaptation effects and from the likelihood of reduced user acceptance of the devices.

While it significantly complicates protocol development and documentation, it may thus be necessary to cast exposure protocols in terms of individual differences in reactivity, that is, to allow each trainee to come as close as possible to threshold, reduce stimulation, and wait for "adaptation" to move the threshold before proceeding further. Such a strategy is consistent with the suggestion by Schmitt and Reid (1985) that adaption in orbital flight can be accelerated by constantly challenging the environment and "backing off" when symptoms become too severe, and was used successfully by Reason and Graybiel (1970) to raise individual tolerances to motion stimuli. This approach of "subject-paced control" is already present in many of the experimental procedures in the PAT Science Plan, but the issue may be central to success and is the recommended procedure in planning device use.

4.3 Training

Although procedures definition for training is likely to be more complex than for familiarization and demonstration, the process and factors to be considered are much the same as those given above for those mechanisms. The role and qualifications of instructors must be addressed, and the pacing and control of exposure must be decided under the same constraints as those for demonstration. Otherwise, the development of procedures involves examining the objectives to be accomplished, devising strategies that are likely to meet those objectives, and, because training is cumulative, specifying the activities to be conducted in each of a sequence of trainer sessions that build systematically on the learning from earlier sessions.

The concept of training as we have developed it here also involves a major element of activity and participation by the trainee, and implies the presence of some task to be performed. Tasks may replicate those from the mission with the intent of providing more direct transfer to inflight performance, or they may be other classes of tasks selected to provide generalized practice in task performance under altered conditions. Factors in the choice of training tasks are much the same as those in choosing measures for evaluation. These are described in Section 3.2.1 and 3.2.2. The presence of a task provides an opportunity for performance measurement. Performance data may be valuable both for tracking training progress and for evaluating the effectiveness of the training system. Requirements and approaches for performance measurement should be specified in the training procedures.

Other than the necessity to accommodate to the above distinctions, the training protocols and procedures and their documentation will closely resemble those for activities earlier in the training cycle. Depending on the ultimate decisions about trainer use, it may be feasible and desirable to combine demonstration and training in some way, i.e., to provide demonstration in a passive sense as an introduction to a particular sensory rearrangement, followed by the more active involvement of task performance in that same altered condition. To the extent that device use is structured in that way, the procedures for demonstration and training may be documented in the same "Operator/Instructor Manual."

4.4 Summary

Several key issues in deciding about PAT use were identified, including a) classroom-oriented versus self-study during familiarization, b) the role and qualifications of instructors during the various stages of instruction, and c) whether the intensity and pacing of exposure will be trainee-paced versus protocol-driven. A set of documentation to guide trainer use was recommended. At a minimum, there should be a technical workbook or text for familiarization, an "Operator/Instructor Manual" for demonstration, and a similar manual for training. Depending on the procedures elected, it may be appropriate to combine the last two documents.

SECTION 5.0
REFERENCES

Berbaum, K. S., Kennedy, R.S., & Welch, R. B. (1986). Relevance of studies of transfer of perceptual-motor training for Space Adaptation Symdrome. Paper presented at VIIth International Man in Space Symposium, Houston, TX.

Cormier, S. M. (1984). Transfer of training: An interpretive review. Technical Report 608. Alexandria, VA: Army Research Institute

Essex Corporation (1988, May). Users manual for the Automated Performance Test System (APTS). Version 5.03 (Draft). Orlando, FL: Author.

Gibson, E. J. (1969). Principles of perceptual learning and development. Englewood Cliffs, NJ: Prentice-Hall.

Graybiel, A., Miller, E. F., & Homick, J. L. (1974). Motion sickness in skylab astronauts. In B. Bhatia, G. S. Chhina, & B. Singh (Eds.), Selected topics in environmental biology. New Delhi: Interprint Publications.

Hettinger, L. J., Lane, N. E., & Kennedy, R. S. (1988). Diagnostic measurement approaches to the problem of sickness in flight simulators. Paper presented at Meeting of American Institute of Aeronautics and Astronautics (AIAA), Atlanta, GA, September 7-9.

Kennedy, R. S., Berbaum, K. S., Williams, M. C., Brannan, J. & Welch, R. B. (1987). Transfer of perceptual-motor training and the space adaptation syndrome. Aviation, Space, and Environmental Medicine, 58 (9, Suppl.), A29-A33.

Kennedy, R. S., Lane, N. E., & Kuntz, L.-A. (1987, August). Surrogate measures: A proposed alternative in human factors assessment of operational measures of performance. Proceedings of the 1st Annual Workshop on Space Operations, Automation, and Robotics (pp. 551-558). Houston, TX: Lyndon B. Johnson Space Center.

Kennedy, R. S., Tolhurst, G. C., & Graybiel, A. (1965). The effects of visual deprivation on adaptation to a rotating environment (NSAM 918). Pensacola, FL: Naval School of Aerospace Medicine

Lane, N. E. (1987). Skill acquisition rates and patterns: Issues and training implications. New York: Springer-Verlag.

Lane, N. E., Kennedy, R. S., & Jones, M. B. (1986, September). Overcoming unreliability in operational measures: The use of surrogate measure systems. Proceedings of the 30th Annual Meeting of the Human Factors Society.

Lane, N. E. (1983, March). Navy issues in chemical/biological warfare defense training. Minutes of the Tenth Meeting of DoD Human Factors Engineering Technical Advisory Group, El Paso, TX.

Lane, N. E., & Kennedy, R. S. (1988, February). A new method for quantifying simulator sickness: Development and application of the Simulator Sickness Questionnaire (SSQ). Technical Report EOTR-88-7 for the Department of Energy. Orlando, FL: Essex Corporation.

Lane, N. E. (1986, April). Issues in performance measurement for military aviation with applications to air combat maneuvering. NAVTRASYSCEN TR-86-008. Orlando, FL: Naval Training Systems, Center.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Parker, D. E., & Welch, R. (1987, November). Preflight Adaptation Trainer (PAT) project science plan (draft). Houston, TX: Space Biomedical Research Institute.

Reason, J. T., & Graybiel, A. (1970). Progressive adaptation to Coriolis acceleration associated with 1-RPM increments in the velocity of the slow rotation room. Aerospace Medicine, 41 (1), 73-79.

Schmitt, H. H., & Reid, D. J. (1985, July). Anecdotal information on Space Adaptation Syndrome. Houston, TX: NASA/Space Biomedical Research Institute.

Shiffrin, R. M. & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Welch, R. B. (1986). Adaptation of space perception. In K. R. Boff, L. Kaufman, & Thomas, J. P. (Eds.), Handbook of Perception and human performance. Vol. I: Sensory processes and perception (Chapter 24). New York: Wiley.