5

Improving Motor Skills

Many strategies can be employed to enhance human motor performance. The Army has already incorporated into military instruction many proven psychological techniques, such as demonstration or modeling, feedback, and reinforcement. The research basis for some of the newer techniques, however, has not been clearly established, although the sponsors of these techniques make claims of extraordinary improvements in performance.

Three strategies are discussed in this chapter: mental practice, visual concentration, and biofeedback. Of the three, mental practice appears to be the most promising. It has been shown to produce impressive gains in performance, gains that are even larger when combined with physical practice. The evidence on visual training exercises is less impressive. While improving vision in general, the exercises have not been shown to enhance performance; however, these results are based on a relatively small research literature, and further investigation may reveal a relation. A larger research literature exists with regard to biofeedback. While the promise of enhancement remains, research on biofeedback to date has largely failed to demonstrate clear effects.

MENTAL PRACTICE

According to Richardson (1967), "mental practice refers to the symbolic rehearsal of a physical activity in the absence of any gross muscular movements" (p. 95). In real life, mental practice is evident, for example, when a golfer closes his eyes and in imagination goes through the motions of putting (Richardson, 1967). In research studies, to create similar conditions, demonstration of a skill to subjects (or having subjects perform the skill a few times) is usually followed by asking students to mentally practice the skill a specified number of times or as many times as possible within an allotted period. Beyond this, the type of symbolic activity is largely unspecified. Some subjects may therefore employ visual imagery of the skill, others may talk their way through the skill, and still others may use a combination of both strategies. The diffuse nature of this construct not only makes it difficult to control experimentally, but also results in the same topic's being investigated under a variety of other names—for example, symbolic rehearsal, imaginary practice, implicit practice, mental rehearsal, conceptualizing practice, and mental preparation.

Most experiments on skill acquisition have been variants of a research design that employs four groups of subjects randomly selected from a homogeneous population or equated on initial levels of performance. These groups are (1) mental practice, (2) physical practice, (3) combined physical and mental practice, and (4) no physical or mental practice (control). Most studies have compared the performances (before and after) of subjects who had previous mental practice to a control group that had not received instructions on mental practice. In the mental practice group, the subjects rehearse the skill in imagination for a set amount of time. Subjects in the control group are instructed not to practice the skill physically or mentally during the interval. A more appropriate control would require subjects in the no-practice group to participate in the same number of practice sessions as the mental and physical practice groups, but with activity that was irrelevant to the task. In many studies, mental practice and control groups are contrasted to a physical practice group and a group receiving combined mental and physical practice. The practice period instituted varies considerably in the number of trials in each practice session and in the total number and spacing of trials. In the combined mental and physical practice groups, practice periods usually involve having subjects either alternate mental and physical practice trials, mentally practice a number of trials and then physically practice, or physically practice a number of trials and then mentally practice. Following this practice period, the subjects' skills were tested under standard conditions to determine whether their performance scores differed as a result of the practice condition administered.

PREVIOUS REVIEWS

Several people have reviewed research examining the effects of mental practice on motor learning and skilled performance on a selective basis. The reviews by Richardson (1967) and Corbin (1972) included 22 to 56 studies and provided contradictory conclusions. Richardson (1967) reviewed studies of three types: (1) those that focused on how mental practice could facilitate the initial acquisition of a perceptual motor skill, (2) those that focused on aiding the continued retention of a motor skill, and (3) those that focused on improving the immediate performance of a skill. He concluded that in a majority of the studies reviewed, mental practice facilitated the acquisition of a motor skill. At that time there were not enough studies to draw any conclusions regarding the effect of mental practice on retention or immediate performance of a task.

Five years later, Corbin (1972) reviewed many other factors that could affect mental practice and was much more cautious in his interpretation of the effects of mental practice on acquisition and retention of skilled motor behavior. In fact, he maintained that the studies were inconclusive and that a host of individual, task, and methodological factors used with mental practice produced different results.

In a 1982 review of "mental preparation," Weinberg reviewed 27 studies dealing with mental practice. Although Weinberg noted the equivocal nature of this literature, he maintained that the following consistencies were apparent: (1) physical practice is better than mental practice; (2) a minimum skill proficiency is needed in order for mental practice to be effective; and (3) mental practice combined and alternated with physical practice is more effective than either physical or mental practice alone. The latter conclusion is similar to Richardson's (1967) cautious inference that the combined practice group is as good as or better than the physical practice trials only.

The most comprehensive review of the mental practice literature to date is that of Feltz and Landers (1983). This study used meta-analysis techniques proposed by Glass (1977). (For a review of these techniques see the paper prepared for the committee by Deborah L. Feltz, Daniel M. Landers, and Betsy J. Becker, Appendix B.) A search of published and unpublished literature yielded 60 studies in which mental practice was contrasted to a simple or placebo control. Collectively, mental practice effects were examined across 50 different tasks, ranging from dart throwing to maze learning. Analysis of the resulting 146 effect sizes yielded an overall average effect size for mental practice of 0.48. Except for the conclusion reached by Corbin (1972), Feltz and Landers's overall findings supported the conclusions of other reviewers that "mentally practicing a motor skill influences performance somewhat better than no practice at all" (Feltz and Landers, 1983:25).

Feltz and Landers also examined several variables believed to moderate the effects of mental practice. Results from these comparisons indicated that larger effect sizes were found: (1) in published compared with unpublished studies; (2) when the posttest was given a longer time after mental practice rather than immediately after; and (3) in studies employing cognitive tasks as opposed to motor and strength tasks. Subsequent polynomial regression analysis revealed that this latter, highly robust finding was dependent on the time or number of trials subjects were allowed to mentally practice. Motor tasks having a substantial cognitive component (i.e., card sorting, pegboard test, maze learning, symbol digit test) benefited from only a few trials or a few minutes' engagement in mental practice. By contrast, when tasks that primarily involved strength or motor components were examined, larger effects were evident only when subjects mentally practiced for 10 or more minutes or 20 or more trials. The results also showed no differences in effect sizes for sex, age, self-paced versus reactive tasks, and type of research design.

Based on their comprehensive review, Feltz and Landers concluded that "mental practice effects are primarily associated with cognitive-symbolic rather than motor elements of the task" and that these effects "are not just limited to early learning—they are found in early and later stages of learning and may be task specific" (1983:45–46). This latter conclusion does not support Weinberg's (1982) conclusion that for mental practice to be effective individuals must achieve a minimal skill proficiency.

The most recent review of the mental practice literature is the paper by Feltz, Landers, and Becker. The majority of the studies (69 percent) reviewed were the same as in the 1983 review, with 14 additional studies. They examined: (1) learning effects by means of effect sizes for pretest-to-posttest differences, (2) mental practice effects compared with no practice, physical practice, and mental and physical practice, and (3) effect sizes using more modern meta-analytic procedures recommended by Hedges and Olkin (1985). Only studies containing complete data for pretest and posttest comparisons were included in the review: as a result, 48 studies for 223 separate samples were reviewed.

The results revealed that the average difference in effect size from pretest to posttest across all types of practice treatments was 0.43 standard deviations and that this differed significantly from zero ($p < .05$). The mean change for all practice conditions was significantly greater than zero, with physical practice showing the greatest change effects (0.79), followed by the combined physical and mental practice group (0.62), and the control group showing the smallest change effects (0.22). The average weighted pretest–posttest effect size for mental practice groups (0.47) was very close to the 0.48 unweighted effect size reported by Feltz and Landers (1983). Contrary to what has been previously theorized in the literature (Corbin, 1972; Weinberg, 1982), combined mental and physical practice does not appear to be more effective than either mental or physical practice alone.

When the overall effects were broken down to examine the moderating variables of task type and type of dependent measure, most of the variation was found in dependent measures of accuracy and time-on-target or time-in-balance and in tasks that were essentially motor (versus cognitive or strength). The failure to find differences for cognitive tasks as well as for speed, distance, and form-dependent measures was due to the insufficient number of samples ($N < 3$) having these characteristics.

Although the physical practice group generally had the highest effect sizes, those of the combined physical and mental practice group were relatively close. For task measures of time-on-target or time-in-balance, the combined practice group actually had a larger difference score effect size than either the physical or mental practice groups. However, this finding is of questionable significance due to the relatively small number of samples and a much larger standard error of measurement.

The fact that many of the tasks in the studies reviewed were gross motor tasks involving accuracy of dart throwing, basketball foul shooting, ball striking, golf chip shots, bowling, and so on lends greater assurance that these findings would generalize to tasks of significance to military performance (e.g., marksmanship). The merging of mental practice with varying combinations of physical practice may lend itself to military applications. For some tasks for which actual physical practice may either be expensive, time-consuming, or physically or mentally fatiguing, the combined practice may be advantageous, since the effects are nearly as good as physical practice with only half the number of physical practice trials. It might be useful in future research to find out whether the gap between physical and combined physical and mental practice could be decreased by increasing physical practice relative to mental practice trials (e.g., a 60:40 or 70:30 ratio of physical to mental practice trials).

Theoretical Explanations for Mental Practice

There are two main theories to explain the effects of mental practice. The first explanation, termed symbolic learning (Sackett, 1934), posits that mental practice gives a performer the opportunity to rehearse the sequence of movements as symbolic components of the task. Most real-life tasks include components of symbolic (verbalizable) and nonsymbolic (perceptual-motor) activity. Given an opportunity for mental practice, covert rehearsal of the symbolic components of the task can occur, and overt practice can strengthen these activities. Thus, according to this theory, mental practice facilitates performance only to the extent that symbolically encoded components are relatively important.

A second type of theory, termed the neuromuscular theory (Jacobson, 1932), posits that it is possible to inhibit peripheral motor activity. This theory suggests that minimal, or low-gain, neuromuscular efferent patterns during imagined movement should be identical (in timing and in muscles used) to those patterns generated during overt movement, but reduced in magnitude. Although no overt movement takes place, this minute innervation, as indicated by electromyography (EMG), is presumed to transfer to the physical practice situation. According to the theory, only a small, localized efferent from imagery is required for visual and kinesthetic feedback to the motor cortex and thus for the motor schema to be further improved (Hale, 1981) or for the corresponding muscle movement nodes to be primed (Mackay, 1981). Conceivably, then, mental practice involves virtually all the neural activity of the overt performance.

There are a number of problems with the neuromuscular theory. The evidence provided in support of it (see Feltz and Landers, 1983, for a review) does not demonstrate that the low-gain EMG activity during mental practice is similar (i.e., in timing and in muscles used) to the EMG associated with overt performance of the skill, and it does not indicate that the presence of low-gain muscle activity during mental practice is related to subsequent task performance. In essence, investigators testing this theory to date have not measured EMG activity during overt task performance and have not measured performance following assessments of EMG activity during mental practice trials (e.g., Harris and Robinson, 1986).

Furthermore, the idea that mental practice involves "virtually all of the neural activity" related to the overt performance is called into question by studies examining regional cerebral blood flow (rCBF) during overt and covert finger movements (Roland, Larsen, et al., 1980; Roland, Skinhoj, et al., 1980). With the assumption that rCBF indicates which part of the brain is being activated, Roland et al. found that, compared with the rCBF associated with programming and control during the actual execution of finger movements, mental practice of the same sequence resulted in some brain regions' not being activated (i.e., primary sensorimotor hand area), and the rCBF in the supplementary motor area's being only 60 percent of the increase observed during actual execution. Thus, it appears that the programming during mental practice is qualitatively and quantitatively different from the programming that takes place during physical practice.

Perhaps the low-gain muscle activity that is commonly observed during mental practice may have nothing to do with programming. It may simply be an artifact associated with "priming" for the upcoming activity (e.g., arousal-attention set, Schmidt, 1982) or the idiosyncratic tendency through imagination of movement for some subjects to produce muscular impulses that correspond to the overtly produced motion (so-called Carpenter effect, Cratty, 1973).

Finally, examination of key experiments (Johnson, 1982; Kohl and Roenker, 1983; Mackay, 1981; Ryan and Simons, 1983) has led reviewers to conclude that the locus of mental practice effects are cognitive-symbolic rather than motor (Annett, 1985; Feltz and Landers, 1983). As summarized by Annett (1985:194):

> What seems to be emerging is that the representations which are most effective in mental practice are of a rather abstract kind, such as spatial context in Johnson's experiments, core meaning in Mackay's experiments, and control rules rather than specific movements in the tracing experiment. If each of these rather different skills is thought of as being controlled by a motor plan then it would appear that rehearsal of critical and invariant elements of the plan which may be represented in imagery is the source of mental practice effects. The executive details of the plan, which may in any case have to be varied from time to time to meet variable conditions, probably contribute little and may not be laid down in a permanent store.

The idea that mental practice effects derive from "rehearsal of critical and invariant elements of the plan" is not the only cognitive explanation for mental practice. Other investigators (Tversky and Kahneman, 1973) suggest an "availability idea," that is, that well-rehearsed images are stored in easily retrievable places in the brain. Greater rehearsal would then allow the image to "spring to mind more quickly" and produce the belief that the image is more likely to occur as a consequence. This latter idea is similar to the idea of "images of achievement," which is currently being promoted as a central concept in a marketed self-improvement program dealing with the "neuropsychology of achievement." This self-help program has been singled out for discussion since it is the most highly developed and influential mental practice program currently being marketed, and it purports to provide a breakthrough in scientific understanding of how and why mental practice and imagery occurs. The general achievement program as well as videotape programs for a variety of sport skills are products of SyberVision® Systems, Inc., Newark, California. A description and evaluation of the scientific bases for these products are presented in the next section.

SyberVision®

On August 29, 1986, two committee members visited SyberVision® Systems headquarters and interviewed Stephen DeVore, founder and president, and Karl Pribram, head of Stanford University's Neuropsychology Research Laboratory and director of research for SyberVision® Systems. The discussion centered on a series of audiotapes called "The Neuropsychology of Achievement" (1986) and a set of videotapes (1981) that concentrates on such sport skills as golf (men's, women's, putting, and driving), skiing (downhill and cross-country), tennis, bowling, racquetball, and baseball batting. The videotape packages include a 60-minute videotape of a well-known professional athlete (e.g., Stan Smith, Al Geiberger, Rod Carew), a personal training guide designed to accelerate learning, and four companion audiotapes: (1) an explanation of how SyberVision® works, (2) teaching tips from the professional athlete, (3) psychological characteristics of winners, and (4) the musical score from the videotape for use in imagery recall.

The tapes are of professional quality, showing a performer repeating the skill over and over. The viewing angle and speed (regular and slow motion) repeatedly change so as to reduce habituation. Occasionally the fundamental movement is amplified and simplified through computer graphics, illustrating the biomechanics of the movement. "Synchronized high performance music" is played throughout the tape; the tempo, rhythm, and timing of the music accentuate the ideal tempo, rhythm, and timing associated with optimal performance of the skill.

The videotapes are designed for three levels of use: (1) casual, recreational viewing, (2) biomechanical reinforcement, and (3) neuromuscular programming. Of particular relevance is their use in neuromuscular programming—a "scientifically formulated" procedure for transferring the high performance skills modeled on the tape into the nervous system of the observer. To do this, the instructional manual recommends: (1) relaxing by using breathing and imagery techniques; (2) watching the tape while emphasizing a whole-body, lower, upper, then whole-body focus; (3) upon completion of the tape, turning it off and with eyes closed imagining each motion about ten times in slow motion or in the computerized graphics mode; and (4) reinforcing the learning by repeated viewing of the fundamental skill. Following this sequence of steps is supposed to facilitate the development of "a fluid and graceful rhythm" in synchrony with the skilled movement on the tape.

The "simple physics of neuromuscular programming" is presented in an appendix to the instruction manual, and there is a more complete description on the first audiotape of "The Neuropsychology of Achievement" program, entitled "Your Holographic Brain: The Power of Three-Dimensional Visualization." According to the audiotape, Karl Pribram has proposed that the hologram "provides the long sought after model of how visual sensory information is received, distributed, stored and recalled by the brain." The tape goes on to say that "there is enough laboratory evidence available to demonstrate physiological, biological and mathematical bases for the model."

The evidence presented points to similar parallels between the holographic model and brain function: (1) memory is distributed throughout the brain in a way similar to a holographic image that is spread over the entire surface of a film plate; (2) a single holographic plate comes closest to matching the storage capacity of the human brain (1 cubic centimeter holds 10 billion bytes of information); and (3) both holograms and the brain can construct three-dimensional images.

According to Pribram's theory of brain functioning, the brain and the nervous system act as a holographic processor by having an equivalent object beam (i.e., the eye, since it represents 95 percent of object reality) and reference beam (i.e., the remaining senses) that interact and create interference patterns (waveforms) of nerve impulses. These nerve impulses are transformed by the brain into electromagnetic waveforms with a unique frequency that represents the exact movement specifications. The decomposition of what is seen and sensorily experienced is accomplished mathematically by the brain's ability to perform a Fourier transform (Instruction Manual, 1981). Once the transformation is completed, the electrical frequency (timing, rhythm, and tempo) associated with the movement is distributed and stored throughout the brain. To recall this stored information, the particular reference beam associated with the object beam is needed to trigger the stored motion frequency, "bring it to the surface of memory and neurally reconstruct the stored memory event" (Instruction Manual, 1981, p. 17). Thus, activities such as looking at old photographs may trigger certain emotions that can act as sensory reference beams to evoke vivid three-dimensional images.

Also included in Pribram's analysis of imagery are principles derived from quantum physics and electromagnetic energy. According to the law of quantum physics, images exist in reality because they are waveforms that possess energy and matter. Thus, the more one visualizes the image along with sensory detail and emotion, the greater the electromagnetic force will be, and the more it will mimic concrete reality.

During the interview, DeVore and Pribram confirmed what a search of the literature had already revealed: that no research could be found testing the efficacy of the SyberVision® tapes. Thus, the sole basis for the relationship of tapes to performance is anecdotal accounts and personal testimony of satisfied customers. Although both DeVore and Pribram wished to encourage research into the use of the tapes for neuromuscular programming, this type of research was not compatible with Pribram's research program, and DeVore was not willing to provide much funding for research.

On the basis of the extensive research literature on mental practice, it is conceivable that programs like SyberVision® could improve performance. However, SyberVision® is a broad-based package that includes elements of modeling and imagery, a training guide, tips from professional athletes, and common psychological characteristics of winners. If performance gains were observed, they could not be attributed to mental practice.

The available research literature on mental practice is consistent enough to support a recommendation for the Army to conduct evaluation studies on operational military tasks. However, packages like SyberVision® should not be evaluated apart from the types of mental practice training that already have an established research base. They should be evaluated only within the traditional mental practice paradigm so their pre-post performance effects can be directly compared with physical, mental, combined physical and mental, and placebo-control practice conditions.

Research evidence for neuromuscular programming via holograms and Fourier transforms is elusive. Other than the claims in the SyberVision® videotapes and audiotapes, no direct scientific evidence was found that the brain acts like a holographic processor or performs Fourier transforms. The research to which Pribram referred us (Pribram, Sharafat, and Beekman, 1984) discusses the possible interpretation of research results in light of the holographic model, but the data did not provide any direct support for the model. At the present time, therefore, the cognitive-symbolic theory still remains the most viable explanation for mental practice effects.

Conclusions

The research generally indicates that mental practice accounts for about half a standard deviation in performance gain over what is observed for controls. When mental practice is examined for motor tasks having significant cognitive components or when it is combined with physical practice, the performance gains are much greater. The explanation for mental practice effects appears to be related to symbolic rehearsal of critical and invariant elements (i.e., control rules) of the motor plan. The research does not indicate support for either Jacobson's neuromuscular theory or Pribram's holographic model as explanations for mental practice.

The overall effectiveness of mental practice supports future research in at least two directions: one is evaluation studies by the Army on operational military tasks; the other is research designed to determine which combinations of mental and physical practice (e.g., 60:40 or 70:30 ratios of physical to mental practice) would best enhance skill acquisition and maintenance, taking into account time, efficiency, and cost.

VISUAL CONCENTRATION

Many military tasks would be enhanced if concentration were improved. Although there are numerous experimental techniques to assess concentration (e.g., the dual-task paradigm and the probe technique), there are so far no concentration- and attention-training techniques derived from experimental research. The training programs designed to develop concentration fall into two categories: (1) cognitive-behavioral techniques (Meichenbaum, 1977) to focus attention better and (2) visual training to develop the eye muscles.

Cognitive-Behavioral Techniques

According to Schmid and Peper (1986), concentration is "the ability to focus one's attention on the task and thereby not be disturbed or affected by irrelevant external or internal stimuli." Within a cognitive-behavioral framework, Nideffer (1976, 1979, 1981, 1985, 1986) has developed what he has called attentional control training. The training consists of cognitive-behavioral techniques such as breathing–muscle relaxation (to control arousal) and mental rehearsal–positive self-talk (to shut out negative self-thoughts).

In this literature (Nideffer, 1985, 1986), attention is conceived as requiring at least two dimensions: width (broad or narrow) and direction of focus (internal or external). Table 1 illustrates four types of activities that would be performed best with a given attentional style. The idea is that, by knowing the types of attentional focus required by the task, attention can be trained and performance improved (Zaichkowsky, 1984).

There are two major problems with this approach: (1) research or evaluation studies comparing the performances of subjects receiving attentional control training and subjects not receiving training have not been conducted, and (2) other than for the broad-narrow dimension (Reis and Bird, 1982), the questionnaire used to distinguish types of attentional focus (i.e., the Test of Attentional and Interpersonal Style, TAIS) has poor validity—both with respect to factorial validity (Dewey, Brawley, and Allard, in press; Rubl, 1983; Vallerand, 1983; Van Schoyck and Grasha, 1981) and construct validity (Aronson, 1981; Jackson, 1980;

TABLE 1 Activities as a Function of Attentional Style

Width of Focus	Direction	
	Internal	External
Broad	Used to analyze and plan	Used to rapidly assess a situation
Narrow	Used to systematically mentally rehearse a performance situation or to monitor and/or control physical arousal	Used to focus in a nondistractible way on one or two external cues

Turner and Gilliland, 1977; Vallerand, 1983; Zaichkowsky, Jackson, and Aronson, 1982). In addition, it has not discriminated between skilled and unskilled performers (e.g., Jackson, 1980; Landers, Boutcher, and Wang, 1986; Zaichkowsky, Jackson, and Aronson, 1982).

Although some people persist in the belief that it may work, there is no scientific evidence that attentional control training and the concepts underlying it help in any way to improve performance. At this point, this approach to improving concentration does not appear to be promising.

VISUAL TRAINING PROGRAMS

Other programs designed to improve attentional skills assume that concentration is a combined visual and mental skill. The basic rationale is that, for those who are free of inherent visual abnormalities, exercises for the muscles surrounding the eye will improve visual abilities and thus enhance performance. It is claimed that, by training visual abilities, efficient eye movements and tracking abilities can be learned, even while the body is in motion (Revien and Gabor, 1981; Seiderman and Schneider, 1983).

The visual training programs have been designed by optometrists. The most prominent names in this field are W. Harrison, L. Revien, P. Irion, A. Seiderman, S. Schneider, C. Farnesworth, and A. Sherman. Some of these programs are designed for specific skills, whereas others have more widespread applications. One committee member who is also a member of the Visual Performance and Safety Committee of the U.S. Olympic Committee was briefed (March 7 and October 25–26, 1986) by L. Revien, C. Farnesworth, and P. Irion on techniques designed to improve visual skills. What follows are descriptions of some representative approaches to training visual skills with the intent of helping people concentrate or attend to a performance task.

These programs begin with a visual screening or testing. For example, comprehensive visual screenings of athletes have occurred at the 1985 and 1986 Sports Festivals, which are national competitions sponsored by the U.S. Olympic Committee. Included are tests for visual acuity (static and dynamic), contrast sensitivity, saccadic fixation, convergence, accommodation, refraction, eye health, depth perception, phoric-tropic posture, central-peripheral visual recognition, visual reaction time (central and peripheral), eye-body-hand coordination, and vision-balance. A detailed description of the visual tests given at the Sports Festival is given in Coffey and Reichow (1986).

The enhancement or training part of the program usually follows the screening or testing. Proponents maintain that, through a program of exercises, eye muscles and perceptual abilities will be improved. This improvement is usually assessed by retesting.

There are several programs designed to improve marksmanship skills. Information on these types of programs was obtained from Craig Farnesworth, who has worked with one of the creators of one such program, Concentrix. Farnesworth provided specific information on the procedures used in these types of programs.

The programs generally have three parts. The first consists of basic visual training. While keeping their heads still, subjects perform tasks involving eye pursuits and tracking, visual accommodation and convergence, saccades, and binocularity (i.e., phorias).

The second part of such programs is called "advanced visual skills." Numbers are flashed on a screen by a tachistoscope, and the subject must locate those numbers by pointing to a position on the screen. Also included in the advanced skills training is mental imagery and practice of the skill in which improvement is desired (e.g., marksmanship).

The final part of such programs is called "enhancement." The primary intent at this point is to produce a sensory overload so that the subject is forced to adapt quickly to the changing visual conditions. Prism lenses are used to provide visual flexibility in adapting to spatial and lighting conditions. For example, while wearing prism lenses subjects are required to throw bean bags at a target on the wall. Although the prism initially produces throws to the left of the target, subjects eventually learn to adjust so that they begin to consistently hit the target. When the prism glasses are removed, the subjects overcompensate and throw to the right of the target. The idea is that with practice on varied tasks, they will be able to adjust more quickly to changing spatial and lighting conditions.

Another type of sensory overload often provided is the performance of visual tasks while the body is undergoing dynamic movement in space. Subjects are required to read eye charts or fire laser guns at targets on the wall while they are doing feet, knee, and seat drops on a trampoline.

The ProVision Training Program

The ProVision Training Program, developed by L. Revien (Visual Skills, Inc., Great Neck, New York), consists of a set of techniques and exercises on an interactive laser videodisc. ProVision involves basic visual training and some, but not all, of the training in advanced visual skills. The training program is designed to improve (1) speed and span of recognition, (2) stereopsis under stress conditions, (3) spatial awareness and judgment, (4) response to visual stimuli, (5) visual concentration, and (6) visual performance in speed situations. For instance, an exercise for improving visual acuity involves focusing on a rotating spiral after which a tennis ball appears on the screen. If the viewer maintains concentration on the spiral, the ball should appear bigger and to move toward one. There is also a three-dimensional version (with 3-D glasses) of the laser videodisc to magnify this illusion. There are other tests for response time, speed of recognition, and hand-eye coordination.

In its promotional material, ProVision is said to improve the "quality, accuracy, magnitude, speed, and smoothness of visual impulses transmitted to the brain." The material also states that ProVision is the "product of many hours of research, experimentation and successful application by hundreds of professionals and athletes who, in every case, found a decided improvement in their visual skills and in their physical and mental performance." The claimed benefits are supported by the testimonials of fighter pilots and the batting averages of professional baseball players. None of this information is presented in a way that is amenable to scientific evaluation. The fighter pilots, known as the Aggressor Group, are from the 64th Fighter Weapons Squadron at Nellis Air Force Base in Nevada; they were given ten training sessions. Their letters evaluating the training program state that the visual performance of all pilots improved on the ProVision tests. Some pilots felt that they had benefited from the training; however, only three thought that their performance in the air had improved, and all but one pilot recommended how future research should be done in order to clearly demonstrate a relation to pilot performance.

In his October 25, 1986, presentation, Revien mentioned that ten members of the New York Yankees baseball team had received ProVision training. The training sessions ended in June 1980. Revien presented performance statistics before (1979) and after (1980) visual training for seven of the ten players (see Table 2). Six of the seven ballplayers showed improvement in batting averages. Between 1979 and 1980, the players receiving visual training improved their batting averages by 14 points, had six more runs batted in, and had two more home runs. Although data on individuals were not available, Revien reported that the batting averages of all other players not given visual training was .239 in 1980.

There are several problems in interpreting these data as a performance enhancement resulting from visual training. No mention is made of whether random assignment was employed. In addition, the number of subjects in the control group is unclear, and there was no control for a Hawthorne effect. To be able to more clearly attribute this performance enhancement to visual training, the performance measures for the control and the experimental groups should be examined before, during, and immediately following the training period. It is also necessary to demonstrate a training effect for specific visual abilities. Thus, given the incomplete presentation of data and the lack of experimental control, it

TABLE 2 Performance Measures Before and After Visual Training for Seven Members of the New York Yankees Baseball Team

	1979				1980			
Player	AVE	AB	RBI	HR	AVE	AB	RBI	HR
Soderman	.262	357	53	10	.287	257	35	11
Dent	.230	431	32	2	.262	489	52	5
Randolph	.270	574	61	5	.294	513	46	7
Watson	.288	475	71	16	.307	469	68	13
Brown	.250	68	3	2	.260	412	47	14
Cerone	.239	469	61	7	.277	519	85	14
Spencer	.288	295	53	23	.236	259	43	13
Means	.261	432	48	9	.275	419	54	11

NOTE: AVE = batting average, AB = at bats, RBI = runs batted in, HR = home runs.

cannot be concluded that the visual training program was responsible for the observed increases in batting averages.

Research Literature on Visual Training

There is a substantial body of scientific knowledge on visual training. In relation to sports performance, 40 studies have been reviewed by Stine, Arterburn, and Stern (1982). Although the review was published in 1982, inspection of the studies since then supports the following conclusions of these authors: (1) good athletes have better visual abilities than poorer athletes; (2) visual abilities (i.e., span of visual field, recognition, motion perception; depth perception; dynamic visual acuity; convergence; heterophoria; and simultaneous vision) are trainable; and (3) visual training has not been conclusively demonstrated to enhance an athlete's ability to perform.

Although studies demonstrate that many visual abilities are trainable, the transfer to real-world tasks that are relevant to sports or the military has not been demonstrated. Stine, Arterburn, and Stern's final comment is germane: "there are no valid, controlled studies that prove a positive relationship between visual training and athletic performance, nor are there any studies that disprove a relationship" (1982:633).

Direction and Design of Future Research

It is intuitively appealing to think that a relation between visual training and performance might be established. Vision is one of the more important senses in task performance, and training of visual abilities related to a task would seem likely to benefit performance. Visual abilities are trainable, but it is not clear whether training can transfer to tasks relevant to the military. A research study should be conducted to investigate whether visual training exercises can benefit military performance. A secondary research problem could be how long (or how frequently) the training needs to be given to affect performance.

Several considerations should be taken into account in the design of such a study. It is first necessary to screen people for inherent visual abnormalities (e.g., astigmatism) that would not be amenable to training. It is also important to identify a specific task (e.g., marksmanship) for which visual abilities are relevant. Relevant visual abilities might be inferred from comparative studies of good and poor performers. Once the relevant visual abilities are known, visual tests should be designed to closely approximate the characteristics of the criterion task (e.g., marksmanship). Too often the visual test bears no relation to the task to which generalization is desired. According to the long-standing principle of specificity of motor skills (Henry, 1968), the visual training tests must be very similar to the criterion task if transfer is to occur.

It is also important that the criterion task be chosen to provide reliable, sensitive measures of performance. Tasks with subjective performance ratings should be avoided in favor of objective scoring on an interval or ratio scale. For example, target shooting could be used as a criterion task if the target size were adjusted to avoid floor and ceiling effects and scored in millimeter deviations from the center of the target. In addition, to avoid Hawthorne effects, it would be advisable to give the control group something that they believe will help their performance and that occupies the same amount of time. Of course, other than varying visual training versus attentional (placebo) control, all other factors should be held constant (e.g., amount of practice, instruction in marksmanship, testing environment, and conditions).

The U.S. Olympic Committee has recently appropriated $43,000 to conduct a visual training and enhancement program with athletes. Some of this money has been earmarked for a research study on the effects of visual training on the performance of shooters and team handball players. The request for proposals is similar to a 1985 proposal developed by P. Vinger. The study was scheduled to begin in February 1987.

Conclusions

With regard to improving visual concentration, cognitive-behavioral techniques do not have a research basis to support the relation between training and improved performance. Nideffer's (1985, 1986) bipolar model, which combines width and direction of focus, has received considerable attention because of its heuristic value in purporting to explain individual differences in attentional style. Research studies using Nideffer's measure of attention (Test of Attentional and Interpersonal Style) have found that it lacks both construct and factorial validity. Thus, the scientific basis for what Nideffer calls attentional control training is severely compromised. At this point, the approach does not appear promising, and further evaluation is not recommended.

By contrast, there does appear to be a research basis for the association between visual training exercises and improved vision. A variety of visual abilities can be improved with training of the muscles controlling the eyes. Because of this association, it is often assumed that skilled performance improves as a result of visual training, but there is no satisfactory scientific evidence to show any relation between visual training and performance. It is conceivable, however, that such a relation could be established, and we therefore recommend that research studies be designed to examine the potential of these techniques for skilled performance.

BIOFEEDBACK

In contrast to the literature on visual concentration, the literature on biofeedback includes numerous studies that lend themselves to scientific scrutiny. Our review of this vast literature is restricted to cognitive and motor performances that might have potential military applications.

Biofeedback is essentially the providing of information about an individual's biological functions. In practice, it consists of training individuals to use instruments, such as polygraphs, computers, and physiological equipment, to provide themselves with feedback on their physiological state so they can *learn* "to make voluntary changes in whatever process is being monitored" (Danskin and Crow, 1981). The goal of this training, often with very expensive equipment, is to eventually allow the trainee to regulate the desired bodily changes without instrumentation.

Although there has been considerable biofeedback research dealing with human performance, it has generally failed to clearly demonstrate biofeedback effects, because (1) the effects of biofeedback are often confused with broader therapeutic techniques, such as progressive muscle relaxation or mental imagery (Benson, Dryer, and Hartley, 1978; DeWitt, 1980; French, 1978, 1980; Gillette, 1983; Peper and Schmid, 1983; Powers, 1980; Wilson, Willis, and Bird, 1981), and (2) the specific performance to be enhanced by means of biofeedback is often poorly described, and therefore only diffuse effects (such as general stress reduction) are anticipated. Research on biofeedback used as an approach to stress management is included in Chapter 7.

A major research thrust is the use of biofeedback for the voluntary control of specific cortical or autonomic responses that are assumed or known to be directly related to specific behaviors. For example, knowing that the tachycardia accompanying exercise causes pain in angina pectoris patients suggests that such patients can be taught to lower heart rate so they can tolerate more strenuous exercise before reporting pain (McCroskery et al., 1978). Examination of studies with known links between cortical-autonomic responses and specific behaviors has revealed much more promising results. Lawrence (1984) has reviewed the biofeedback research in areas such as rifle shooting, playing stringed instruments, problem solving, sensory thresholds, learning (reaction time), sleep, manual dexterity in cold environments, and motion sickness. With the exception of problem solving and sensory thresholds, in which EEG biofeedback was employed, Lawrence's review revealed that, compared with a control group, subjects trained in biofeedback techniques performed better. He concluded that for military applications "some promise exists in learned control of specific internal events for specific performances."

A problem with the evidence presented in Lawrence's review is that most of the research consists of single studies that have not been replicated. And in some instances, the authors' subsequent reports (Daniels and Landers, 1981; Finley, Karimian, and Alberti, 1979; Finley et al., 1978; Ford et al., 1980; Landers and Christina, 1986; Sheer, 1977, 1984) failed to replicate initial findings. In what follows, we update many of the topics previously reviewed (Lawrence, 1984; Lawrence and Johnson, 1977; Rockstroh et al., 1984), and include topics not presented in the previous reviews. We discuss the research that has been conducted on each of the following types of feedback: electromyography (EMG), EEG, heart rate (HR), respiration, thermal self-regulation, and multiple autonomic responses.

Electromyography

Several studies have been designed to improve performance by decreasing muscular tension. It is assumed that, by reducing general bodily tension or tension in specific muscle groups to "desirable levels," greater economy of muscular energy would be evident and performance would be enhanced. By providing information about tension that individuals cannot normally perceive, it is maintained that EMG biofeedback can supplement normal proprioceptive mechanisms until they become sufficiently sensitive to provide voluntary control over tension (Basmajian, 1974).

EMG biofeedback training has been used to enhance musical skills, increase hip flexibility to prevent hamstring injury, improve sprinting performance, and improve hand-eye tracking and lateral balancing performance (see Table 3). With few exceptions (Cummings, Wilson, and Bird, 1984; Griffiths et al. 1981; Wilson and Bird, 1981), these studies have shown that EMG levels in the targeted muscle group were reduced more in persons receiving feedback than in controls; however, these results must be viewed cautiously, since feedback effects were not significantly different from those of placebo controls (i.e., relaxation-meditation) (Cummings, Wilson, and Bird, 1984; Griffiths et al., 1981; Wilson and Bird, 1981). In this research it does not appear that EMG biofeedback training has any greater tension-reducing benefits than variants of Jacobson's (1938) progressive muscle relaxation training.

The performance results were equally unimpressive. Only two of the ten studies showed limited support for biofeedback effects on performance. Wilson and Bird (1981) found that improvement in hip flexibility occurred more readily with biofeedback compared with controls, but they were unable to replicate this in a second experiment. Sabourin and Rioux (1979) found that subjects trained in "active" biofeedback (i.e., producing different levels of tension) performed better on memorizing nonsense syllables, rotary pursuit, and simple reaction time. However, subjects undergoing the usual EMG biofeedback procedure of lowering tension levels (called "passive") had significantly lower reaction time performance than controls. Even more revealing were the nonsignificant correlations between EMG levels and performance scores (Blais and Vallerand, 1986; Cummings, Wilson, and Bird, 1984; French, 1980; Morasky, Reynolds, and Sowell, 1983). These findings basically confirm the conclusion derived from Lawrence and Johnson's (1977) review of studies supported by the Defense Advanced Research Project Agency (Smith, 1975; Stoyva and Budzynski, 1973; Tebbs et al., 1974), which found that EMG biofeedback offers little promise for performance enhancement in stressful situations.

This conclusion applies to the existing research in general, which is based on the assumption that lowering muscle tension to a previously undefined level will enhance performance. As Lawrence and Johnson (1977) point out, this is a naive assumption, since muscle relaxation may be maladaptive in many situations requiring a sudden and vigorous physical response.

Surprisingly, none of the investigators cited in Table 3 determined a priori what the desirable level of muscular tension should be for the specific performance task examined. For example, the Morasky et al. studies of musical performance did not compare advanced versus beginning musicians to determine muscular differences that might suggest

TABLE 3 Electromyography Feedback (EMG FDBK) Training and Its Effect on Various Performance (PERF) Measures

Primary Investigator	Subjects	Experimental Conditions	Site Trained	Training Duration	Performance Measure	Results
Morasky et al. (1981)	9 stringed instrument players	(a) FDBK (b) No FDBK	Left forearm extensors	Four 2-hour sessions	None	None
Morasky et al. (1983)	8 clarinet players	(a) FDBK (b) No FDBK	Left forearm extensors	Four 1-hour sessions	Trills/scales	No PERF differences
Wilson et al. (1981)						
Study I	10 gymnasts	(a) FDBK (b) Self-RELAX	Hip extensors (biceps femoris)	9 sessions over 3 weeks	Hip flexibility	PERF improved in both groups, but was quicker in FDBK group
Study II	18 gymnasts	(a) RELAX + FDBK (b) RELAX (c) Control	Hip extensors (biceps femoris)	8 sessions over 3 weeks	Hip flexibility	No flexibility differences among groups
Cummings et al. (1984)	30 sprinters	(a) FDBK (b) RELAX (c) Control	Hip extensors (biceps femoris)	Eight 10-minute sessions over 4 weeks	Hip flexibility, 50-meter sprint	FDBK and RELAX groups had more hip flexibility than control subjects during retention; no group differences in sprinting PERF
Blais (1986)	20 boys ages 10–13	(a) FDBK (b) Placebo	Frontalis muscle	6 sessions over 2 weeks	Stabilometer lateral balancing task	No PERF differences

French (1978)	30 college men	(a) FDBK during training and posttest (b) FDBK during training (c) No FDBK	Frontalis muscle	Nine 20-minute sessions[a]	Stabilometer lateral balancing task	No FDBK effects on PERF (group A = group B)
French (1980)	30 college students	(a) FDBK during training and posttest (b) FDBK during training (c) No FDBK	Frontalis muscle	Nine 20-minute sessions[a]	Rotary pursuit, tracking task	No FDBK effects on PERF (group A = group B)
Sabourin and Rioux (1979)	18 female volunteers	(a) "active" FDBK (b) "passive" FDBK (c) Control	—	Five 30-minute sessions	Nonsense syllables, simple reaction time, rotary pursuit, tracking task	Active FDBK better than control for all PERF tasks; passive FDBK only better than control for rotary pursuit
Griffiths et al. (1981)	50 college students	(a) FDBK (b) Meditation (c) Control	Frontalis muscle	Six 20-minute sessions over 3 weeks	Puzzle assembly task performed underwater	No PERF differences among groups

[a] These sessions included, in addition to auditory EMG biofeedback, progressive relaxation and autogenic training methods. In order to demonstrate a biofeedback effect on PERF, the group receiving feedback during training and posttest (group A) would have had to perform significantly better than the group receiving feedback only during the training sessions (group B).

specific types of feedback training (Morasky, Reynolds, and Sowell, 1983; Morasky, Reynolds, and Clarke, 1981). Earlier work by Basmajian and White (1973) established that, compared with expert trumpet players, beginning players have greater tension in the upper lip than in the lower. Although it has not been investigated, the implication is that improved performance may result from feedback training to suppress the difference in lip tension. Unfortunately, such preliminary EMG comparisons of experts and novices prior to feedback training are not found in this research. As a result, determining which muscle or combination of muscles should be trained and what the criteria should be before training is completed is pure guesswork. Under such circumstances, it is not surprising that this research has yielded very little to suggest a performance enhancement due to EMG biofeedback.

Electroencephalography

This section provides an overview of the research on cerebral self-regulation via biofeedback training. We address the behavioral significance of self-regulation of electrocortical parameters, namely, spontaneous EEG activity, event-related potentials, and slow potentials.

Spontaneous EEG Activity

Spontaneous EEG activity refers to signals elicited without a specific eliciting event or stimulus. Early feedback research on an EEG band, referred to as alpha (8 to 12 hertz), showed positive results (Kamiya, 1969; Mulholland, 1962). Initial enthusiasm led investigators to suggest that alpha enhancement facilitated task performance (Nowlis and Kamiya, 1970), improved delayed recall (Green, Green, and Walters, 1969), raised pain thresholds (Gannon and Sternbach, 1971), and shortened the time needed for sleep (Regestein, Buckland, and Pegram, 1973).

Following the first positive results, however, careful methodological examinations of alpha biofeedback (e.g., Paskewitz and Orne, 1975) dampened much of the initial enthusiasm (for reviews see Johnson, 1977; Lawrence and Johnson, 1977; Rockstroh et al., 1984; Yates, 1980). Although subjects could be trained to change the amount of alpha time or amplitude, this rarely produced changes above the prefeedback baseline. It appears that the previous reports of alpha increases were simply a return to baseline after (arousing) attention had been withdrawn from experimental procedures or the feedback display. According to Lynch and Paskewitz (1971:213), "alpha activity occurs in the feedback situation when an individual ceases to pay attention to any number of stimuli which normally block his activity."

The basic question of interest has been whether alpha enhancement will affect behavioral responses. A connection between alpha enhancement through biofeedback and performance has not been consistently demonstrated (for reviews see Johnson, 1977; Lawrence and Johnson, 1977). Enhanced alpha activity has not been related to performance in a short-term memory task or a choice reaction-time task (Beatty, 1973; Kamiya, 1972), nor has it been related to maze learning and perceptual-motor coordination (Levi, 1976). Similarly, alpha training was not related to performance on more complex cognitive tasks requiring any degree of effort (Orne et al., 1975). Finally, alpha enhancement does not prevent sleep loss or substitute for sleep (Hord et al., 1975; Hord et al., 1976), does not provide a recuperative break period (Kamiya, 1972), and does not result in significant pain reduction (Melzack and Perry, 1975).

Based on this evidence, the conclusion reached by Lawrence and Johnson (1977) that training in alpha enhancement does not seem to enhance performance is convincing. It may be that alpha activity represents electrophysiological background activity that is either unrelated to behavioral processes or regulated independently of them (Rockstroh et al., 1984).

An alternative explanation is that the effects of alpha enhancement have been masked by methodological inadequacies or the inability to find relevant behavioral variables. For example, some preliminary data indicate that greater success in solving arithmetic problems has been achieved by feedback on alpha wave *suppression* (Jackson, 1978). Alpha feedback has also been shown to be related to verbal or spatial task changes by localized training of the appropriate cerebral hemisphere. Murphy, Lakey, and Maurek (1976), for example, found that right-handed subjects trained to increase left brain EEG and decrease right brain frequency produced an enhancement in verbally solved arithmetic problems. The relation between right brain alpha and spatial task enhancement was also positive but not significant.

In order for such an approach to be effective, it must be studied further using more sophisticated methodology. One of the problems in studies of hemispheric function is that tasks should not be differentiated on the basis of crude vernacular descriptions of complex psychological processes. According to Gale and Edwards, "mental arithmetic may be seen to be verbal (because the subject has to make calculations) but it may also be seen to be spatial (because the subject may move the digits about in his mind's eye on an imaginary piece of paper)" (1983:120).

Specifying tasks that are appropriate to the psychological processes of interest would solve one methodological problem in EEG biofeedback; other methodological problems must also be addressed. Reviews by Plotkin (1976) and Yates (1980) emphasize the need for better understanding of the oculomotor characteristics (e.g., eyes open–eyes closed, ambient illumination), instructions to subjects about strategies of control, and several issues regarding measurement of alpha. In summarizing the existing research, Yates indicated that "alpha research is, methodologically speaking, in a state of considerable disarray. Rarely can so much effort have been expended for so little result" (Yates, 1980:309).

Another EEG band, occipital theta (3.5 to 7.0 hertz), has been related to an ability to maintain vigilance (Beatty et al., 1974). Such a relation would be important for processing information during monotonous, repetitive tasks in unstimulating environments (e.g., industrial inspection and radar monitoring). In vigilance tasks, a performance decrement usually occurs as a function of time spent continuously monitoring. With one exception (Daniel, 1967), early correlational investigations (Groll, 1966; Williams et al., 1962) showed that, during monotonous monitoring, more theta was observed in the period preceding misses than in the period preceding correct detections. Since the amount of theta activity generally present was found to be unrelated to reaction-time performance (Williams et al., 1962), it might be indirectly related to performance by reflecting changes in arousal level. Beatty and O'Hanlon suggested an activation hypothesis that predicts "that performance should deteriorate as the level of nervous system activation declines over time in the task" (1979:247).

Beatty et al. (1974) provided experimental support for the activation hypothesis. Using operant procedures to regulate occipital theta of college students, these investigators found that suppression of theta enhanced monitoring efficiency, whereas theta augmentation resulted in a deterioration in monitoring efficiency over a two-hour period. These initially very favorable results were not totally supported in subsequent experiments. In a later study using a one-hour vigilance task, Beatty and O'Hanlon (1979) found that subjects trained to reduce theta performed no better than a nonfeedback group. Although the theta-suppressing subjects did detect signals more rapidly than the theta-augmenting subjects, the magnitude of these effects was greatly reduced. Beatty and O'Hanlon (1979) suggested that the monitoring task may not have been long enough to produce a performance decrement, which could be lessened by a suppression of theta. Their results implied that suppression of theta does not increase the level of performance beyond one's capabilities under alerted conditions, but rather retards any existing vigilance decrement.

Other studies (see Lawrence and Johnson, 1977, for a review) conducted in operational environments found either weakened effects (Beatty and O'Hanlon, 1975) or no effects at all (Hord et al., 1975; Morgan and Coates, 1975; Beatty and O'Hanlon, 1975). Considering that many of these studies examined trained naval radar observers, air controllers, and sonar operators, the findings cast considerable doubt on the benefits of this research for performance in situations relevant to the military.

The conclusion reached by Lawrence and Johnson is appropriate (1977:169):

> . . . theta suppression may prevent or lessen performance decrements that are typically found in vigilance tasks of long duration. A performance decrement may be a necessary condition for the observation of theta effect, and there are no data to suggest that theta suppression can lead to performance enhancement above initial levels.

This may be the only performance benefit accruing from theta suppression. However, this optimistic appraisal must be viewed with caution until further work is done to establish better reliability and robustness in operational environments.

Event-Related Potentials

Several investigators have studied the relationship between operant control of various event-related potentials (ERPs) and behavior. ERPs refer to common features of brain potentials that are time-locked to an evoking or eliciting event. These potentials are usually labeled with regard to their latency (in milliseconds) from the evoking stimulus. For example, N100 describes a negative wave with a peak after about 100 milliseconds and P300 a positive wave that peaks after about 300 milliseconds.

In this research, behaviors (such as sensory-motor threshold and pain sensitivity) are studied as dependent variables to determine if they change as a function of modification of brain potentials through operant techniques. As pointed out by Lawrence (1984), such central nervous system phenomena could potentially contribute to performance on tasks having low-amplitude signals. Thus, if auditory ERP latencies could be decreased by means of biofeedback techniques, this would be interpreted clinically as reflecting improved hearing.

Operant control of early brain stem potentials (20 to 40 milliseconds), particularly wave V (P8-N1) of the auditory potential and sensory-evoked potentials (N14-P22), has been demonstrated (see Finley, 1984, for a review). In these studies, one group received contingent visual feedback, and their ERPs were compared with those of a yoked, noncontingent control group. Although the contingent feedback did not consistently show significant effects on latency of the ERP components (e.g., Finley, Karimian, and Alberti, 1979), the feedback group achieved significant differences in the amplitude of component V on the second and third days of training. These findings were later replicated. Finley (1984) has also demonstrated an increase in amplitude and a decrease in latency for sensory and motor thresholds (as measured by current intensity necessary to evoke a sensation or thumb twitch) of spine-injured patients showing sensory-motor deficits in the upper extremities.

Similar results have been achieved by other investigators (Roger, 1984; Roger and Garland, 1983) with visually evoked potentials (VEPs). Compared with pseudoconditioned controls, 51 percent of the subjects were given feedback to learn to modify VEPs. As in the above-mentioned studies examining auditory- and sensory-evoked potentials, some subjects who received feedback never learned the task. Roger (1984) found that the personalities of the learners may have been different; they scored higher than nonlearners on restraint, emotional stability, objectivity, and cooperativeness.

Sensitivity to pain has also been modified following operant conditioning of evoked potentials from the orofacial pain path. Rosenfield and coworkers (1984) trained rats to increase or decrease the segments of a potential evoked by electrical shocks to the facial trigeminal nerve (surface P20-70). As a result of this training, the typically observed facial rubbing following shocks to the whiskery area of the face occurred later and less often. Similar results have been found with humans when several feedback-trained subjects decreased both P200 amplitude and pain sensitivity. From their series of studies, Rosenfield et al. (1984) concluded that: (1) the conditioning is localized to that cortical area to which reinforcement contingency is explicitly applied; (2) the correlated perception of pain is localized to the body surface tissue represented in the conditioned cortex; (3) not all body surface areas can be affected by biofeedback of ERPs; and (4) the conditioning of ERPs modified a true pain-evoked component, since its habituation can be blocked by the endorphin-inhibiting drug naloxone.

In summary, several biofeedback studies demonstrate that sensory (auditory, visual), motor, and pain thresholds can be altered by operant feedback techniques. The statistical and methodological rigor demonstrated in most of these studies tends to rule out experimental artifacts as mediators of these behavioral results. It is also quite clear that not all feedback-trained subjects are able to learn control of the ERPs. This naturally limits the widespread applicability of these results to military personnel. For those who can benefit from ERP biofeedback, future research should determine if performance would be improved on operational tasks necessitating decreased auditory, visual, motor, or pain thresholds.

Slow Potentials

Slow potentials refers to the characteristic slow negative potential shifts (DC shifts) recorded from the scalp that are often observed during waiting periods prior to an alerting stimulus (e.g., the preparatory interval in a reaction-time paradigm). This type of potential occurs whenever two stimuli are associated, or contingent, in that the first stimulus (i.e., warning stimulus) signals an upcoming response or information processing required for the second, imperative stimulus. Slow potentials can be positive or negative. The negative slow potential, often referred to as an expectancy wave or contingent negative variation, is considered to be a state of preparation or mobilization of cerebral resources for response anticipation or information processing. By contrast, positive slow wave shifts are believed to reflect a consumption of resources (Birbaumer et al., 1981).

Research has shown that negative slow potentials are associated with better performance than zero or positive shifts. For example, for choice reaction-time (RT) performance, negative shifts in the frontal electrode site were associated with faster and less variable responses (Stamm, 1984). Compared with positive shifts, choice RTs following negative slow potentials were up to 53 milliseconds faster. On the other tasks (e.g., word matching), faster responses were associated with negativity, compared with positive pretask shifts in the parietal location (Stamm, 1984). Furthermore, performance on stimulus-response pairs (number and syllable) was better following negative slow wave shifts (Bauer, 1984). This research demonstrates the effectiveness of negative slow wave shifts on task performance and suggests specificity in the relation between type of task and the location of the negative shift—the cerebral area assumed to contribute to task performance.

Using a paradigm involving feedback generated by movement of a stylized representation of a rocket ship across a television screen (see Elbert et al., 1979, for a detailed description), research has shown that within 80 to 160 trials human subjects can learn to deflect this rocket ship upward or downward by self-regulating their slow wave polarities (Elbert et al., 1980). Subjects were able to learn to control slow potentials without any conscious knowledge about the dependent variable in the biofeedback design (i.e., their own slow cortical potentials). In addition, generalization of control was demonstrated, since subjects were also able to maintain control during trials without continuous feedback. However, slow wave differentiation was reduced when task difficulty was increased.

A comparison of autonomic, muscle tension, and subjective reports indicated that subjects who relied less on somatovisceral maneuvers and more on cognitive strategies (i.e., imagery, thoughts, concentration) were more successful in achieving large differences on tasks requiring negativity than on tasks requiring positivity of the slow wave signal. According to Rockstroh et al. (1984), this latter finding suggests that in these cases the brain regulates itself by brain processes rather than by peripheral mediation.

Considering that negative slow potentials are assumed to indicate preparatory processes to activate brain regions needed for the anticipated task, subjects operantly trained to self-regulate negative potential shifts would be expected to perform better on a variety of tasks. In a series of studies, Lutzenberger and colleagues (Lutzenberger et al., 1979, 1982; Rockstroh et al., 1980, 1982) were able to show that, with feedback to increase rather than decrease slow wave negativity, subjects (1) pressed a button faster (mean RT difference, 13 milliseconds) on transfer trials, (2) checked the solutions of moderately difficult arithmetic problems more quickly (mean latency difference, 6 seconds), and (3) deteriorated less on a 240-trial vigilance task of signal detection performance. It also appeared from the signal detection results that a moderate amount of slow wave change (−5 millivolts) was optimal for best performance, whereas no shifts or shifts greater than −10 millivolts resulted in poorer signal detection.

A recent study (Lutzenberger et al., 1985) found that the preparatory negative slow wave potentials were hemisphere-specific when stimulus input, processing, and motor output were lateralized. It was also shown that this lateralized response could be learned via feedback procedures and that RTs were improved with feedback from the right hemisphere. Rockstroh et al. (1984) suggest that the performance benefits are brought about by the activation of brain regions involved in the task rather than by a modulation of unspecified arousal systems.

The relation between slow wave potentials and performance on a variety of tasks has been observed enough times to promote reasonable confidence in its validity. The effects appear to involve brain regions known to be involved in performance of the task, and the magnitude of the performance differences appears to be impressive enough to warrant further research in operational environments. As pointed out by Lawrence (1984), it is not always clear from these studies "whether the improved performance on any given trial reflects increased slow wave negativity during that trial, or rather ensues from, say, a cumulative effect of previous trials where slow wave negativity has been achieved" (p. 12). In determining its usefulness for relatively simple operational tasks, it would be helpful to know the characteristics of voluntarily regulated slow wave shifts during and immediately preceding performance on a given trial.

Further research is also needed to determine if extended biofeedback or more sophisticated training techniques can overcome the present limitations of relatively poor slow wave differentiation of more complex tasks. Unless this limitation is overcome, self-regulation of slow wave potentials may be incompatible with simultaneous performances which exist in many operational tasks.

Heart Rate

It has been established that individuals can exert control over heart rate (HR). Unlike voluntary control of EEG parameters, nearly all subjects have shown success in controlling HRs by means of cardiac feedback. There is also some evidence (Harris, Stephens, and Brady, 1974; Stephens, Harris, and Brady, 1972) to indicate that voluntary HR increases are easier to achieve than HR decreases.

While extensive research literature exists on exteroceptive feedback effects on HR control, most of this research is directed toward general reduction of arousal rather than enhancement of performance. For review purposes, the performance-based research that is available has been grouped into two areas: (1) HR self-regulation effects on concurrent task performance and (2) HR feedback effects on the economy of effort in performing static and dynamic exercise.

Concurrent Task Performance

In a series of studies, Harris and his colleagues (Harris, Stephens, and Brady, 1974; Stephens, Harris, and Brady, 1972; Stephens et al., 1975) examined whether (1) engaging in concurrent tasks modified voluntary HR control and (2) if this ability to control HR affects concurrent task performance. Harris, Stephens, and Brady (1974) compared subjects trained to raise or lower HR to a rest condition on their ability to perform simple RT tasks, vigilance tasks, and mental arithmetic problems. They found that all subjects could perform the RT and vigilance tasks satisfactorily without interfering with HR self-regulation. For the RT task and for one of the vigilance tasks (i.e., Mackworth Clock Vigilance), there were no discernible effects of HR self-regulation on task performance.

Harris, Stephens, and Brady (1974) also examined vigilance on the Continuous Performance Task. The subject's task was the identification of the letter "x" from among various letters presented every two seconds on a display in front of them. In one part of this study (see Brady et al., 1974), the previous HR control conditions (increase, decrease, and rest) were examined under stressful (i.e., electric shock) and nonstressful conditions. Across all 13 subjects, the accuracy of response (i.e., percentage correctly identified) was not affected by the biofeedback conditions. However, response time to identify the letter "x" was longer when HR was lowered, it was shortest when HR was raised, and it fell between the two when HR was in the rest condition.

Under conditions of stress, subjects could no longer decrease HR, and their ability to increase HR was approximately half that observed under nonstress conditions. As expected, performance accuracy dropped under conditions of stress. Compared with the 73 percent drop in the rest treatment, performance accuracy fell to 60 percent during periods requiring HR decreases. By contrast, under conditions of HR raising, the decrements associated with the stressful electric shocks were virtually eliminated. Harris, Stephens, and Brady (1974) believed that the elimination of the performance decrement as a result of HR raising demonstrated the potential for autonomic self-regulation in reducing performance decrements due to aversive stress. According to Lawrence and Johnson (1977), the relationship of voluntary HR control and task performance under stressful conditions should be studied further.

Economy of Effort in Static and Dynamic Exercise

A recent area of scientific inquiry has been the use of biofeedback to modulate the HR response to exercise. Until now, only therapeutic implications have beeen drawn from this research for the potential benefit of patients with hypertension or angina. However, enough HR biofeedback has been done with healthy human subjects to suggest that physical capacity (both anaerobic and aerobic) might also be enhanced. Although this research has not examined whether subjects trained to control HR can exercise longer, the majority of studies (see Table 4) has shown that subjects trained to self-regulate HR have greater economy of effort in accomplishing the same amount or duration of physical work. This would appear to have potential relevance for many military situations in which sustained physical work may play a significant role in quality of performance.

The effect of HR feedback in attenuating the tachycardia associated with exercise has been consistently demonstrated with dynamic exercise (Fredrikson and Engel, 1985; Goldstein, Ross, and Brady, 1977; Lo and Johnston, 1984; Perski and Engel, 1980; Perski, Tzankoff, and Engel, 1985; Talen and Engel, 1986). In these studies, subjects performed at submaximal levels (75 percent of maximum predicted HR) by either walking or running on a treadmill, pedaling on a bicycle, or performing isotonic weight lifting. Compared with no-feedback control subjects, subjects provided with beat-to-beat information (feedback) about cardiac rate were able to lower HR from 5 to 21 beats per minute while they were engaged in dynamic physical exercise. Where measured, ventilation data suggested improved efficiency, since subjects in the experimental group had a tendency to use less oxygen late in training (Fredrikson and Engel, 1985; Goldstein, Ross, and Brady, 1977; Perski and Engel, 1980; Perski, Tzankoff, and Engel, 1985). These effects were interpreted as learning rather than physical conditioning, since there was no reduction in HR in the control groups exercising without feedback (Fredrikson and

Engel, 1985; Perski and Engel, 1980; Perski, Tzankoff, and Engel, 1985). Furthermore, studies indicate that attention (Perski and Dureman, 1979) and instructions (Lo and Johnston, 1984) can be ruled out as factors mediating the HR training effect.

The evidence for HR attenuation during static muscular work, compared with that during dynamic exercise, is not as consistent. Although subjects trained to increase HR while engaged in varying levels of muscular work have consistently been successful in increasing it above exercise-only levels (Carroll and McGovern, 1983; Clemens and Shattock, 1979; Magnusson, 1976; Moses, Clemens, and Brener, 1986), attempts to train subjects to decrease HR have produced equivocal results. For example, Clemens and Shattock (1979) found that subjects trained in HR biofeedback were also able to decrease HR while engaged in static handgrip exercise at 10, 30, and 50 percent of maximal isometric contraction. Moses, Clemens, and Brener (1986) used the same levels of exercise but did not find that subjects were able to modulate the tachycardia of exercise. In their study, HR control (particularly decreases) was progressively impaired as the exercise demands increased.

A point of current debate concerns whether the above-mentioned static and dynamic exercise findings can be interpreted as evidence for cardio-specific control. With the exception of the Goldstein, Ross, and Brady (1977) study, studies examining dynamic exercise have found that blood pressure does not change; the only apparent training effect appeared to be specific to the target response (HR) of the training (Fredrikson and Engel, 1985). Aside from blood pressure, however, the studies examining ventilation have supported the interpretation that the cardiac changes imposed on exercise were largely nonspecific, involving parallel changes in oxygen consumption and respiratory patterns. Moses et al. (1986) maintain that none of the experiments on static and dynamic exercise supports "the inference that individuals may learn to modify the normal tissue-perfusion functions of the heart" (p. 519). Instead, in most of the studies HR has been closely associated with metabolic rate.

Respiration

As pointed out in the previous section, respiratory factors parallel the HR attenuation that is believed to result from HR feedback during exercise. Although the major research emphasis has been on cardiac feedback, the potential significance of respiration biofeedback for economy of effort in exercise is just beginning to be understood. In fact, it has been suggested by B.D. Hatfield (personal communication, December 16, 1986) that subjects may be able to modulate respiration more easily than HR during exercise.

TABLE 4 Heart Rate Feedback (HR FDBK) Training and Its Effect on Various Measures

Primary Investigator	Subjects	Experimental Conditions	Training Duration	Performance Measure	Results
Fredrikson and Engel (1985)	12 borderline hypertensives	(a) Beat-to-beat FDBK (b) No FDBK	5 days, 25 trials	Cycling HR	FDBK reduced exercise HR 10 beats per minute (bpm)
Talen and Engel (1986)	3 monkeys (*macaca mulatta*)	(a) Exercise only (b) Exercise and FDBK (beat-to-beat)	6–15 weeks, 4 sessions per day	HR while lifting weights	FDBK reduced exercise HR 21 bpm
Lo and Johnston (1984)	36 healthy college students	(a) Verbal instructions to lower HR and blood pressure (b) Interbeat internal FDBK (c) FDBK product of "b" and pulse transit time	4 sessions, each with five 6-minute trials	Cycling HR	Product FDBK reduced exercise HR 5 bpm

Perski and Engel (1980)	10 young, untrained subjects	(a) FDBK (b) No FDBK	Five 45-minute sessions	Cycling HR	FDBK reduced exercise HR 15 bpm
Perski et al. (1985)	10 healthy, conditioned men	(a) FDBK (beat-to-beat) (b) No FDBK	4 sessions, each with 5 exercise trials	Cycling HR	FDBK reduced exercise HR 5 bpm
Moses et al. (1986)	20 college men	(a) FDBK (b) No FDBK	Three sessions	Static arm force	No differences between FDBK and control group
Goldstein et al. (1977)	18 adult volunteers	(a) FDBK during exercise (b) No FDBK	10 weekly sessions, five 10-minute trials	Walking on treadmill at 2.5 miles per hour, 6% grade	After 5 weeks, group receiving HR FDBK during exercise had lower HRs (12 bpm) than group with no FDBK
Clemens and Shattock (1979)	8 college men	(a) HR FDBK increase (b) HR FDBK decrease (c) No FDBK	4 consecutive daily sessions, 1-hour duration	Static handgrip of 10%, 30%, & 50%	Subjects demonstrated bidirectional HR control, even with elevated baselines induced by muscular effort

The efficacy of respiration feedback was recently investigated by Hatfield et al. (1986). In this study, 12 aerobically trained athletes were provided with ventilatory feedback on a digital display updated every 15 seconds. With regard to the HR biofeedback studies, the exercise was of greater intensity (i.e., just below calculated ventilatory threshold). A within-subjects design was employed, with subjects receiving, in random order, three conditions (feedback, control, and distraction) during a 36-minute run. The distraction condition consisted of a coincident (anticipation) timing task with timing feedback given every 3 to 4 seconds. During the control condition, subjects were instructed not to attend to feedback of any kind.

The results revealed that the metabolic cost of the run was undifferentiated across conditions. However, minute volume and ventilatory equivalent were significantly reduced with feedback compared with the control and distraction, which were not differentiated. Similar results were found for pressure of end tidal O_2 and CO_2 inhaled by producing relatively more CO_2 with each expiration.

Although this is only a single study, the results are consistent with the running economy results found for HR feedback. Taken together, these results demonstrate that feedback procedures can alter metabolic efficiency during intensive activity in trained athletes. These results are particularly impressive considering the near maximal intensity of the work performed. Considering the magnitude of the effects at high levels of exercise intensity, it would be useful in future research to compare HR and respiratory feedback in modulating a number of physiological and biochemical parameters associated with exercise.

Thermal Self-Regulation

Although many clinicians have found thermal training useful as an aid in treating migraine headaches, frostbite or frostnip, and Raynaud's and other vasoconstrictive disorders, thermal self-regulation with biofeedback may have other cold-weather applications as well (Kappes and Mills, 1985; Taub, 1977). For instance, it is known that extrinsic warming of the hands improves manual efficiency and reduces pain in conditions of extreme cold stress (Lockhart, 1968). In order to perform effectively in cold environments, it is necessary to preserve surface finger temperature to prevent a loss of both tactile sensitivity and dexterity. With obvious implications for the military, Kitching, Bentley, and Page (1942) have examined the usefulness of insulation in increasing hand temperature. Unfortunately, such attempts have often been counterproductive for performance, since heavy insulation often obstructs movement and decreases hand efficiency. Thus, it would be advantageous if hand warming in operational environments could be achieved by other means. One alternative that has gained attention recently is the use of biofeedback to increase hand temperature.

Research on the self-regulation of hand temperature in cold environments (see Table 5) has shown, with few exceptions, that feedback training of digital skin temperature can slow a loss of peripheral skin temperature. In the three studies examining performance (Hayduk, 1980, 1982; Kappes, Chapman, and Sullivan, 1986), the ability to maintain hand temperature resulted in increased performance. For example, Hayduk (1980) was able to train six subjects to increase skin temperature by 5.64°F, and this increase was found to be related to decreased pain as well as improved performance on measures of manual and finger dexterity, hand strength, and tactile sensitivity. A one-year follow-up (Hayduk, 1982) confirmed that these same subjects maintained their learned ability to self-regulate hand temperature. Unfortunately, the interpretation of feedback effects in the Hayduk studies is confounded by training consisting of both classical conditioning and biofeedback components. However, other researchers have achieved the same temperature (Kappes and Chapman, 1984; Kappes, Chapman, and Sullivan, 1986) and performance (Kappes, Chapman, and Sullivan, 1986) results as Hayduk, even when training had been restricted to biofeedback practice accompanied by a relaxation audiotape.

With the exception of the Donald and Hovland (1981) study, the studies listed in Table 5 trained and tested subjects' thermoregulatory abilities inside controlled temperature chambers with total body exposure. Training of this type has led to much better transfer of temperature self-regulation to cold environments than studies that have trained subjects in warm environments with only their hands exposed to cold stress (Donald and Hovland, 1981; Simkins and Funk, 1979; Stoffer, Jensen, and Nessett, 1977). Comparisons of indoor and outdoor environments have shown that skin temperatures of subjects trained outdoors increased, while subjects trained indoors could only maintain their temperatures when tested in an outdoor environment (Kappes and Chapman, 1984). By contrast, the temperatures of the control subjects continued to go down in the cold environment. Although the results of this study suggest a thermal specificity of the training environment, subsequent work has failed to confirm this finding (Kappes, Chapman, and Sullivan, 1986).

It has yet to be determined if the impressive performance gains achieved with hand warming can generalize beyond the resting state. Future research needs to determine if self-regulation of hand temperatures can be of operational use in situations in which subjects are more physically active, have greater cognitive load, or are exposed to additional forms of stress (i.e., competition, combat, and so on). It would also appear that

TABLE 5 Thermal Feedback (FDBK) Training and Its Effect on Body Temperatures and Various Performance Measures

Primary Investigator	Subjects	Type of Cold Environment and Temperature	Training Methods and Design	Results: Average Temperature Change	Results: Pain Self-Report	Results: Performance
Hayduk (1980)	6	1 experiment in cold chamber; +6.8°F	Classical conditioning (warm water); FDBK = 4.4 hours; imagery/ ABA design	+5.64°F	Decreased pain	Increased finger and manual dexterity; greater strength and tactile sensitivity
Zeiner and Pollack (1981)	10	1 experiment in cold chamber; +68°F	FDBK = 3.33 hours; increase versus decrease baseline design	No reliable increase	—	—
Donald and Hovland (1981)	30	Modified refrigerated target limb; +50°F, +75°F, +100.4°F	FDBK = 20 minutes; increase versus decrease design with augmented relaxation	+0.570°F; −0.414°F	—	—

Hayduk (1982)	6	1 experiment in cold chamber; +6.8°F	1 year follow-up of 1980 study; ABA design	+5.7°F	Same as 1980 study	Same as 1980 study
Kappes and Chapman (1984)	25	Arctic tent in outdoor environment; tent temperature, +52°F; outside temperature, +42°F	FDBK = 4 hours, plus twice daily practice in outdoor versus indoor; tested outdoors pre and post	Outdoor, +3.0°F; indoor, +0.0°F; control, −2.6°F	—	—
Kappes et al. (1986)	48	2 experiments in cold chambers: +37°F and +50°F	FDBK = 4 hours in a 2×2×2 pre- and postdesign; counterbalanced by sex, room temperature and time of day	37°F: FDBK +0.80°F, Cont. −0.60°F; 50°F: FDBK +1.70°F, Cont. −0.20°F	Decreased pain	Increased finger and manual dexterity

biofeedback research on performance in cold environments (mountaineering and skiing, as well as operational tasks important to the military) should examine subjects' accuracy in recognizing hand temperature. The protocols used in the studies in Table 5 did not call for subjects to be trained in the specific skill of temperature estimation; instead, they were trained to increase temperatures by relaxing. Thus, when asked to estimate their peripheral skin temperature, subjects were uniformly inaccurate (Kappes and Chapman, 1984). Perhaps discrimination could be improved by having subjects, as part of the training protocol, report subjective changes in skin temperature.

Multiple Autonomic Responses

There are a few examples in the research literature of biofeedback for which more than one autonomic response has been given. One study examined the combined effects of feedback and open-focus attention training (a cognitive relaxation procedure) on economy of effort in bicycle ergometer work (Powers, 1980). The four subjects in this study were given 20 sessions of EMG and temperature feedback–open-focus attention training following baseline sessions to determine oxygen consumption, heart rate, and systolic blood pressure. To demonstrate acquisition of skill, subjects had to reduce mean EMG levels as well as finger and toe temperature to preestablished criteria.

The Powers results indicated that all but one subject had significantly improved efficiency of pedaling the bicycle ergometer. For all subjects, the percentage reductions from pretest to posttest were as follows: heart rate, 8.35 percent; oxygen consumption, 11.75 percent; and systolic blood pressure, 9.35 percent. Although the magnitude of these findings is impressive, the failure to employ a placebo control group and the confounding of biofeedback with open-focus training limits a strictly biofeedback interpretation for the findings. Despite these limitations, Powers suggested that the mechanism for the biofeedback self-regulation process

> . . . may be an organization by means of attentional cortical open focusing leading to bilateral brain hemisphere synchrony; this, in turn, promotes trophotropic processes of the limbic and midbrain area, normalizing the regulatory centers of the hypothalmus, autonomic nervous system, and reticular activating system. (1980:3928-B)

According to Powers, the end result is a state of homeostasis that facilitates optimal functioning.

In an interesting series of studies by Cowings and associates (Cowings, 1977; Cowings, Billingham, and Toscano, 1977; Cowings and Toscano, 1977, 1982), a training method involving biofeedback, autogenic therapy (Schultz and Luthe, 1969), and distraction from symptoms was employed to deal with problems associated with the onset of motion sickness. Cowings (1977) found that, compared with either biofeedback or autogenic therapy alone, the combination produced larger magnitude, less variable response changes that were more stable over time. The 12-day training method, called "autogenic feedback training" (AFT), also accounts for individual response stereotypy (Lacey et al., 1963) by often presenting up to four simultaneous sources of autonomic feedback (heart rate, respiration rate, blood-volume pulse, galvanic skin response, or intercostal muscle activity). The subjects could choose the feedback (auditory or visual) for the given autonomic variable most relevant to their own autonomic response to the motion sickness experienced before testing. The AFT method is believed to deal directly with the final common path of autonomic manifestations of motion sickness, and thus it should work equally well when the underlying mechanisms are different (e.g., Coriolis acceleration affecting the semicircular canals and linear acceleration affecting the otolith organs).

To create nausegenic stimulation by means of Coriolis acceleration, Cowings employed a rotating chair (6 to 30 revolutions per minute) combined with 45° head movements. Experimental subjects given AFT training were able to withstand the stress of Coriolis acceleration significantly longer than control subjects (Cowings, Billingham, and Toscano, 1977). The findings were the same whether subjects were initially found to be moderately or highly susceptible to Coriolis acceleration (Cowings and Toscano, 1982). Symptoms of motion sickness were alleviated for subjects given AFT training only when compared with subjects performing a distracting task (Black Jack task) or no task at all (Toscano and Cowings, 1982). In this latter study, five of the six subjects undergoing AFT training either significantly reduced or totally suppressed symptoms.

A recent study by Dobie et al. (1986) showed that a treatment combining biofeedback (EMG and temperature) and cognitive-behavioral therapy (confidence building and desensitization) was effective in increasing tolerance to stimulation-eliciting motion sickness. However, when the separate effects due to biofeedback versus cognitive-behavior therapy were examined, only the cognitive-behavior group increased tolerance to stimulation and reported less symptomatology than the biofeedback and control groups. This could suggest that biofeedback may have little to do with Cowings's findings. However, Dobie et al. (1986) interpreted their findings as perhaps due to (1) the minimal stimulation experienced in their study; (2) not basing feedback on the unique type of autonomic distress experienced by subjects during pretest acceleration tests; and (3) not exposing the feedback and control groups to similar adaptive exposures of visually induced motion, as given to the combined and cognitive-behavior groups. Considering these design and procedural variations, it is difficult to conclude much from the Dobie et al. findings. It may be that biofeedback is only efficacious if the symptoms are severe or if the relevant autonomic response system is known and then specifically trained in each individual.

CONCLUSIONS

Two major problems appear repeatedly throughout the research on biofeedback and performance. One problem, which limits any clear interpretation of biofeedback effects, is the use of biofeedback as part of broader therapeutic techniques, for example, biofeedback plus classical conditioning (Hayduk, 1980, 1982) or autogenic therapy (Cowings, Billingham, and Toscano, 1977). The other problem, primarily evident in studies examining training in EMG, EEG (alpha or theta), and HR while subjects are performing tasks, is that no prior knowledge is available concerning what the most desirable levels of EMG, EEG, or HR should be to produce optimal performance on the tasks of interest. In other words, the training criteria were not based on EMG, EEG, or HR levels known to be important for effective task performance.

In the areas in which biofeedback has shown more consistent performance benefits, the relations between, for example, ERP and various thresholds, slow wave potentials and readiness to respond to various tasks, HR or respiration and running economy, and hand warmth and finger dexterity, have been established by previous research. Thus, the direction and magnitude of the physiological parameter to be trained could be more clearly established. Provided subjects could be trained on the particular physiological measure, a performance enhancement was generally found. Until more is learned about the most effective EMG, EEG (alpha or theta), and HR levels for the execution of particular tasks, biofeedback research in these areas should not be pursued.

Although the biofeedback research on event-related and slow wave potentials, HR slowing during exercise, and hand warming has been more consistently related to performance enhancement, specific problems must be addressed before these techniques can be implemented into military training programs. For instance, more research needs to be conducted on the most efficacious training programs for producing a greater percentage of subjects who can be trained. In addition, the generality of the laboratory-generated relations needs to be tested in operational environments important to the military. It needs to be determined if the fairly robust effects found in the laboratory can extend to performance of more complex tasks having greater cognitive load or while physically active subjects are exposed to additional forms of stress (e.g., competition or combat). Further research is also needed to train subjects to determine when EEG, HR, and temperature levels are inappropriate for task performance so the self-regulation process can be initiated.

Finally, the performance effects of biofeedback need to be compared with other performance-enhancing techniques (e.g., autogenic training, relaxation, imagery, knowledge of performance or results). In reviews comparing biofeedback with relaxation training, Silver and Blanchard (1978) concluded that there was no consistent advantage of one form of treatment over the other across all of the psychophysiological disorders examined. Even though certain types of biofeedback have been shown to improve performance, biofeedback has not been shown to work better than some other, less costly techniques. In addition to determining what technique is most efficacious and cost-effective, future research also should consider what technique is most efficient (works faster), durable (beneficial effects hold up longer), generalizable (benefits a larger proportion of people), and convenient (easier to administer and easier to perform) (Silver and Blanchard, 1978).

SOURCES OF INFORMATION

Our conclusions are based on several sources of information that were made available to the subcommittee. The literature on mental practice was reviewed according to meta-analysis procedures in the Feltz, Landers, and Becker paper prepared for the committee. In addition, the subcommittee received briefings from practitioners involved in the development of visual training exercises. Useful information was also conveyed by product developers during site visits. These visits enabled subcommittee members to better understand how training programs are developed from certain assumptions about psychological processes, some of which may have a basis in the research literature.