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BIOFEEDBACK AND PERFORMANCE: AN UPDATE

George H. Lawrence

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Open scientific literature on biofeedback and performance is surveyed and evaluated. Use of biofeedback to elicit general relaxation or lowered arousal is probably useless for performance enhancement. Some promise exists for training specific internal events relevant to specific cognitive or motor performance.

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FOREWORD

The effort reported here represents one beginning for the new ARI program to assess the state of the art and evaluate the potential development of technologies designed to extend and enhance quality and productivity of performance for the individual soldier or civilian.

If successful, the use of biofeedback for such techniques may well prove to exemplify the essence of program intent. For instance, the learned ability to use biofeedback to bring oneself into a state of readiness for quick and accurate cognitive response, or for the performance of a complex muscular activity, would, ideally, involve no equipment and, perhaps, could generalize to a wide variety of useful and important purposes.

This review of relevant scientific efforts to date, and the conclusions drawn therefrom, should stimulate further basic studies and developmental efforts in this important area of investigation.

EDGAR M. JOHNSON
Technical Director

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BIOFEEDBACK AND PERFORMANCE: AN UPDATE

EXECUTIVE SUMMARY

Requirement:

To improve efficiency and quality of individual performance by assessing and evaluating the potential of biofeedback for development of relevant technology.

Procedure:

The history of efforts to use biofeedback for enhancement of human performance is reviewed, and a variety of recent research results are presented and critiqued.

Findings:

Internal events fed back to subjects include: several brain frequencies and events; EMG; heartrate, peripheral vasoconstriction, and other autonomic events; respiration. Performance is measured on tasks involving gross and fine motor control, response to a variety of induced stressors, cognitive and psychomotor behaviors, and athletics.

Major conclusions indicate that when mediated via a diffuse hypothetical construct biofeedback has little effect upon performance. However, some promise exists for enhancement through learned control of carefully identified internal events related to specific dimensions of performance.

Utilization of Findings:

Recommendations are made for further research and development designed to bring laboratory achievements into operational use.

BIOFEEDBACK AND PERFORMANCE: AN UPDATE

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INTRODUCTION AND BACKGROUND

There has been no recent review of efforts to enhance human performance through the use of biofeedback, although interest and activity have continued in a number of directions. The purpose of this paper is to survey the literature over the last several years in the hope that a basis has developed for a technology for using biofeedback to assist individuals in the performance of tasks relating to a wide variety of military occupational roles. To be useful, such a technology should provide training methods through which people can learn to exercise more efficient control over bodily functions, and regulate physiological events in such a way that efficiency of overt, measureable behavior will be maximized. This requires an understanding of relationships between internal process and overt performance, learned ability to regulate that process, and demonstration that the results enhance end products sufficiently to justify various costs in time and attention required for training and for operational exercise of the learned techniques. Current military job requirements encompass such a wide variety of gross physical, fine motor, and cognitive skills that nearly any paradigm relating learned self regulatory ability and overt behavior may have potential applicability. Since the appearance of previous reviews of the literature on biofeedback and performance several research paradigms have emerged which may offer promise.

In 1976 (Lawrence) and 1977 (Lawrence and Johnson), results of several studies were reported and discussed and the potential effectiveness of biofeedback as a tool for improving quality or quantity of task-related behavior was judged at that time to be minimal. The experiments then considered were largely designed to test the general hypothesis that voluntary control of physiological events could confer the ability to bring on, in oneself, physical, emotional, and/or cognitive states with which those events are normally concommitant, and which themselves either constitute, or are the bodily substrate for, specific behaviors of interest.

Most of the studies reported in these early reviews attempted control of stress-induced internal events, and to relate such control to improvement in ability to maintain or improve ongoing performance despite anxiety, perceived threat, conflicting attentional demands, or fatigue. Stress was induced variously, via sleep deprivation (Morgan and Coates 1975), shock (Orne and Paskewitz 1974), perceived threat of dangerous hyperbaria (Smith 1975), upsetting visual stimuli (Stoyva and Budzynski 1973), pain (Melzack and Perry 1975), localized hypothermia (Taub 1977), and evaluative observation by superiors (Tebbs, Eggleston, Prather, Simondi, and Jarboe 1974). Even more diverse samples of performance were observed: in addition to a spectrum of more-or-less standard laboratory measures of vigilance, simple and complex reaction time, signal detection, and other cognitive and motor tasks, tolerance for pain, piloting skill, and manual dexterity were also employed.

Results for the most part were disappointing. Although laboratory subjects trained to suppress EEG THETA (the 4-7 Hz sinusoidal cortical wave observed when subjects are drowsy) were, for example, able to avoid the performance decrement normally occurring during a prolonged signal detection task (Beatty, Greenberg, Deibler and O'Hanlon 1974), this effect did not appear under operational conditions (Beatty and O'Hanlon 1979, Beatty and O'Hanlon 1975, O'Hanlon and Beatty 1975). In separate studies (Stoyva and Budzynski 1973; Smith 1975), muscle relaxation training through biofeedback showed no effect upon ability to perform a wide variety of cognitive, motor, and vigilance tasks under diverse conditions of stress including exposure to noise, gory and disturbing photographs, simulated hyperbaria, and fear.

Another study (Tebbs et al 1974) showed that for student pilots previous training in muscle relaxation with biofeedback was associated with superior performance on a check flight. There were, however, no instructions to use this training during the flight nor was there concurrent monitoring of EEG (electroencephalography, or brain waves).

Somewhat more promising was the observation by Harris, Stephens, and Brady (1973-74) that self regulated increases in heartrate eliminated a performance decrement (a CER, or conditioned emotional response) elicited by presentation during trials of a paired clicker-shock stimulus. This finding has not, apparently, been explored further although the subsequent literature contains references to lack of behavioral effect from heartrate regulation in other experimental paradigms. A stable and potentially useful effect was noted by Taub (1977) in the ability of subjects to dilate peripheral vasculature under very cold conditions, although the successful application of this phenomenon to motor performance was not clearly demonstrated.

Generally, these studies were interpreted to offer little promise for the use of biofeedback in the development of techniques for improvement of performance under stress. Consistent with a long standing pattern in psychological research, convincing demonstration of reliable relationships between specific internal events and specific task performance proved elusive. Further, positive laboratory results tended to disappear when tested under conditions more similar to operational settings and when more operationally relevant tasks were employed. Conclusions based upon early reviews were generally not sanguine, e.g., "So far this research (has) failed to identify specific configurations of physiological events that have unique and reliable concommittance with specific psychological or behavioral states of interest and that can be controlled for the purpose of eliciting these behaviors" (Lawrence 1976), and "the results ... offer little support for the initial goal of using voluntary regulation of physiological events to enhance performance" (Lawrence and Johnson 1977). Fortunately, these negative evaluative comments have not universally discouraged subsequent investigators.

Published work on the use of biofeedback for improvement of performance has proceeded under two major thrusts: biofeedback training, often as part of a broader treatment, for induction of a general, diffuse effect (frequently relaxation or lowered arousal); and the use of biofeedback for voluntary control of specific internal events assumed to be directly related to specific behaviors (see Figure 1).

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GENERAL, DIFFUSE EFFECT: USUALLY RELAXATION TRAINING, TO LOWER AROUSAL LEVEL.

SPECIFIC EFFECT: CONTROL OF INTERNAL EVENT(S) RELATED TO PARTICULAR BEHAVIORS OF INTEREST.

Figure 1. Major research thrusts for use of biofeedback to improve performance.

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BIOFEEDBACK AS GENERAL ANTI-STRESS TRAINING

The proposition has long been well accepted that ability to reduce muscular tension and general arousal is beneficial to health, specifically when responding to a broad spectrum of stress (Budzynski, Stoyva, Adler, and Mullaney 1973, e.g.), and this belief underlies current clinical use of biofeedback in stress management programs and in treatment for anxiety-related disorders. The rationale for this is succinctly stated by Rice, Blanchard, and Purcell (1983) and is quite similar to the general hypothesis underlying the earlier programatic work attempting to link biofeedback and performance. It "arises from the premise that the motoric-behavioral manifestations and subjective reports of anxiety can be reduced or controlled". Generally, the results of tests of diffuse effects of biofeedback-induced relaxation have not been positive (Figure 2).

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PERFORMANCE	FEEDBACK	EFFECT
athletics	EMG(usually)	mixed(impossible, usually, to isolate effect of biofeedback)
bicycle exercise	EMG, O_2	minimal-to-none
psychomotor tasks	EMG	slight
reaction to induced stress	EMG, EEG	none
skilled complex motor tasks	EMG	significant

Figure 2. Attempts to improve performance by using biofeedback for general relaxation.

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Biofeedback has been used by itself as a means for inducing relaxation to enhance athletic performance (see Sandweiss 1980) as well as performance on a variety of laboratory tests, and for these purposes as part of a broader armamentorium. Using biofeedback for induction of relaxation usually means voluntary reduction of skeletal muscle tension, with training typically restricted to frontalis. This practice may reflect a methodological problem, since evidence is equivocal with regard to the validity of inferring general muscle relaxation from lowered frontalis EMG (electromyography; an electrical signal generated by muscle tension) . For Arnarson and Sheffield (1980), e.g., frontalis relaxation generalized to heartrate, finger temperature, respiration, and buccinator muscles (though not to forearm flexor). Suarez, Kohlenberg and Pagano (1979), on the other hand, in a post hoc analysis of clinical records of patients with disorders mostly related to anxiety, and whose muscle tension was measured at a number of sites (frontalis, masseter, neck, unilateral and bilateral trapezius, temporal, forearm, and jaw) during relaxation and "cognitive stressor" periods, found that their results "do not support the assumption that frontalis muscle activity reflects general bodily tension".

A paper by DeWitt (1980) well exemplifies the use of biofeedback for improved athletic performance. Two studies are reported, one on college football players judged to "exhibit high stress levels before or after games" and another with college basketball players somewhat more randomly selected. EMG biofeedback was provided for several major muscle areas and heartrate training was added, apparently, for the basketball group. Included in the treatment battery were a desensitization procedure, Jacobsen's progressive relaxation training, mental rehearsal exercises, and other cognitive procedures aimed at causing subjects to "become aware of their typical responses to environmental events and then to substitute more adaptive ways of responding to these environmental conditions". No control group was used in the football study; for the basketball study a "contact control" group was used, and raters "were blind to the training program".

Results indicated that experimental subjects significantly lowered muscle tension and, for the basketball players, heartrate. Coaches and trainers reported significantly improved performance ratings following training, and the players themselves stated in followup conversations that "they felt emotionally more relaxed, in greater control over tension, and felt generally 'looser' during games" - all of which are familiar subjective comments made by subjects after successful relaxation training. There were, also, apparently consistent observations that minor injuries were less common during this training for both groups.

It should be emphasized that in this experiment the specific effects of biofeedback alone on performance, if any, cannot be assessed, but general treatment effects upon muscle tension and heart rate were shown, and biofeedback played a major role in the treatment presentation in both experiments. It is difficult, however, to feel complete confidence that the raters, who were coaches and trainers, were completely ignorant with regard to which of their players had received the experimental treatment. Further, no effort seems to have been made to control for placebo or Hawthorne effects; either or both may have contributed to the observed results.

Peper & Schmid (1983) describe a somewhat similar program, with similar effects, for gymnasts. However, no measures were employed beyond subjective reports from subjects, and other parameters are not well controlled. Other efforts applying combined cognitive and biofeedback training to athletic performance have been reported for skiers and figure skaters (see DeWitt 1980).

A general presumed beneficial effect of biofeedback training for exercise or work performance has been increased metabolic efficiency. Benson, Dryer, and Hartley (1978) have reported lowered oxygen consumption during exercise, brought on by the "relaxation response", training for which included biofeedback. Powers (1980) found in his dissertation a simliar though slight effect, using a cognitive relaxation procedure, training of several autonomic nervous system events, and performance on a bicycle ergonometer. Wilson, Willis and Bird (1981), however, found no effect upon O_2 consumption during a run, from elicitation of a relaxation response by trained subjects.

Cohen & Knowlton (1981) searched for metabolic effects using EMG (site unspecified) biofeedback with subjects, also using a bicycle ergonometer. While the details of this experiment as reported are unclear, even as to whether O_2 was directly measured on test trials (it was, apparently, during pretesting), the authors conclude that their findings demonstrate "a reduced energy requirement in response to the training", and "that EMG-BFT can be used by young men to reduce the energy requirement of completing standardized submaximal work". Interestingly, perception by subjects of exertion expended during these exercises was not affected by the experimental treatment (EMG biofeedback).

Parsimony would seem to require that cases where self regulated relaxation is accompanied by reduced O_2 consumption be interpreted as net conservation of muscle activity, until otherwise demonstrated. It may well be that rather than achieving more output per unit O_2, subjects simply learn to eliminate extraneous, unmeasured effort (see French 1978;1980, discussed below).

In an effort to compare the effects of "active" EMG training (producing various levels of tension, and differential relaxation) versus "passive" (steady maintenance of low tension level), Sabourin and Rioux (1979) measured performance on standard laboratory tasks: memorization of nonsense syllables, simple reaction time, and rotary pursuit. Generally, biofeedback groups performed better than controls (relaxation training but no biofeedback); the authors suggest that more powerful effects might have been achieved through selection of more tense subjects or use of induced stress. The most promising effect was noted in rotary pursuit where both active and passive biofeedback groups continued to improve performance over sessions; the active group did significantly better than the passives.

Gillette (1983) reported that self regulation of EEG ALPHA (a 8-12 sinusoidal cortical wave observed when subjects are relaxed but alert), with OPEN FOCUS training (a cognitive relaxation procedure), resulted in better performance in rod and frame and in pursuit rotor tasks, but not for reaction time. Subjects reported "much reduction in stress symptoms". No test of ALPHA effects alone were possible, since all subjects received OPEN FOCUS training in addition to ALPHA biofeedback. Levi (1976) found no differences in image learning, digit span, or digit symbol resulting from raising or lowering EEG ALPHA; no data are presented with regard to ALPHA production specifically during the trials.

The data from this last group of studies are hardly definitive, but their mixed results and the relatively small magnitude of effects seem to support the notion that diffuse effects of EMG or EEG ALPHA feedback upon performance are slight if any. For the results considered so far, the most positive inference to be drawn may be that a general lowering of arousal may offer some enhancing effect to performamce of some complex motor tasks, and that this conclusion is somewhat more solid when based upon muscle tension feedback training than upon EEG ALPHA control. As Sabourin and Rioux point out, however, most subjects undergoing laboratory experimentation are not usually (in the absence of specific treatment to the contrary) operating under high levels of tension or anxiety. One might expect boredom to diminish performance, and indeed reduction of muscle tension may be counter-productive when baseline levels are already low.

Using a rationale similar to that of Smith (1975), several recent studies have been undertaken to test the hypothesis that diffuse effects of biofeedback training (not easily distinguishable from effects of garden-variety relaxation training) may be useful in coping with emergent environmental stress.

Griffiths, Steel, Vaccaro and Karpman (1981) compared the performance of three groups on on a complex anxiety-producing underwater assembly task. One experimental group was trained to relax with EMG biofeedback and the other via a non-biofeedback meditation procedure; a single control was a group untrained in relaxation. It is not clear what instructions if any were given to subjects regarding relaxation or other means of coping with anxiety during test trials. Although significant negative correlations were reported between performance and scores on scales designed to measure state and trait anxiety, no other effect was significant. In other words, relaxation training could not be shown useful in performing this task.

Nielson and Holmes (1980) tested EMG training for control of arousal elicited by a film of dental surgery. There was no main effect for treatment; apparently subjects did not learn to control muscle tension. The authors consider noteworthy, however, a finding that even though a learning effect did not occur the subjects previously exposed to EMG training showed lower arousal when anticipating the posttreatment stress film than did other subjects. This effect is interpreted as consistent with reports from other studies that subjects trained to relax with EMG biofeedback, while unable to diminish headache once it begins, can sometimes achieve avoidance through anticipatory relaxation. It should be noted that in the Nielson and Holmes experiment there was no significant EMG control during arousal, nor was any effect of EMG training found in subjective reports of arousal levels during stress, or on ability to handle stressful situations. In fact, during the film (as opposed to the anticipation period) the biofeedback subjects exhibited higher levels of EMG than the other groups - perhaps interpretable as postponement rather than avoidance of response to this stress.

Shellman (1980) found no effect upon subjective rating scale indices of anxiety in response to an "arousal tape" (the nature of which was unspecified) for EMG-trained, "relaxation response"-trained, or no-treatment control groups.

Overall, diffuse effects of biofeedback as a means of performance enhancement do not appear to offer much promise except, perhaps, for athletics and then only as part of a more general program. It may be useful to consider the assumptions and rationale for the above and similar studies (and for much of the clinical use of biofeedback). Nielson and Holmes (1980) provide a useful discussion of three basic premises: 1)EMG training is a good way to learn deep muscle relaxation, 2)EMG training will generalize to a broader group of muscles and/or other components of arousal, and 3)EMG training will promote an overall "antistress response" which can be employed at will. (Nielson and Holmes refer to "EMG biofeedback-assisted relaxation training" in regard to the latter two premises, but the implication is that EMG biofeedback is the major active ingredient.)

Evidence is mixed on the advantages of EMG training as a means of learning muscle relaxation, but there is no evidence that it is a dependable shortcut; it appears to be about as effective for relaxation training as other standard techniques. Although there is some evidence that EMG feedback employing limited sites can contribute to other aspects of bodily relaxation it should be remembered that Suarez et al (1979), when specifically measuring effects on other muscle groups, found little generalization from frontalis training (perhaps the most common site when EMG is used to induce general body relaxation). Finally, there is little evidence of success in training subjects to elicit an anti-stress response when stress has been induced, let alone demonstration of performance enhancement under high arousal.

A slightly different focus by French (1978) has led to more positive results. His experiments are aimed not at performance enhancement through use of a diffuse anti-stress effect, but rather at direct benefits from lowered muscle activity. On the assumptions that skilled complex performance results from conservation of muscular tension and controlled minimal application thereof, and that "presence of (excess) residual tension causes one, in effect, to work against oneself", French devised a tension-control method employing various muscle-relaxation techniques, including EMG biofeedback. He found (1978) that for gross motor skill (stabilometer balancing), this training significantly improved time-on-balance scores over those of an untreated control group. Further, significant negative correlations were found between this performance measure and concurrently recorded EMG, offering support for the view that excess muscle tension is deleterious to performance. In a later study (1980) French showed that acquisition of a fine motor skill (pursuit rotor) was similarly enhanced by similar tension-control training.

The results of French's work suggests that if the relationship between muscle tension and performance of a particular task is known and relatively simple, voluntary reductions in general bodily tension can be useful. Results from other studies indicate that such reduction is much more difficult under stress; further, not enough is known to identify optimum levels of muscle tension and arousal for maximum performance under various environmental conditions. It would be interesting to see data for O_2 consumption for these subjects before and after they learn to reduce extraneous EMG.

BIOFEEDBACK MATCHED TO SPECIFIC PERFORMANCE OR BEHAVIOR

Interesting results have been achieved from recent work designed to train subjects to control discrete internal events for improving circumscribed behaviors without explanatory recourse to an intervening variable such as relaxation or lowered arousal (Figure 3).

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PURPOSE	FEEDBACK	EFFECT
rifle shooting	breathing, heartrate	significant
string instruments	specific EMG	significant
cognitive	40Hz EEG, EEG/Alpha	none
sensory thresholds	EEG/ALPHA	mixed
learning, reaction time	EEG evoked potentials	significant
sleep	EEG cortical slow potentials	significant
manual dexterity in cold	finger temperature	significant
motion sickness	EMG	significant

Figure 3. Attempts to improve performance by using biofeedback to train specific internal events.

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Daniels and Landers (1981) first identified specific problems experienced by several expert rifle marksmen, and then provided biofeedback training to assist changes in length of breath-hold, heartrate, and the point within heartrate cycle when the trigger is released. Changes in these parameters and improvement in subsequent target scores were observed. Response pattern consistency improved and subjects reported increased awareness and control of the relevant internal events.

EMG biofeedback for specific muscles relating to specific performance has been employed successfully for string players (Morasky, Reynolds and Clarke 1981) and clarinet players (Morasky, Reynolds and Sowell 1983). Here the aim was to produce an optimum level of tension at a particular muscle site; too much or too little would impair performance, as would generalization to other muscles. This purpose stands in contrast to the general tension reduction used by French; similarly, however, a positive effect was acheived. It is possible that both approaches have merit; it would be interesting to see the effect of reduction of general bodily tension (not relaxation training) on Morasky's musicians. It should be noted also that subjects in the Morasky et al work were practicing musicians rather than paid or student-volunteer subjects, and doubtless felt considerably more interest and motivation than is frequently the case for experimental subjects.

Efforts to show enhanced cognitive performance resulting from attempted control of EEG frequency or amplitude have met with mixed success. Sheer (1977) reported significant improvement for all of his subjects on percent correct solutions to problems after 40Hz conditioning, a frequency associated with problem solving, learning, and attention to stimulus input. However, Sheer in a later paper (1984), and Ford, Bird, Newton and Sheer (1980), were unable to elicit voluntary control over 40Hz activity during problem-solving in trained subjects. Unsurprisingly, performance on cognitive problems was unaffected by instructions to increase or decrease 40Hz activity.

In a dissertation study by Newton (1976), increased subjective arousal and concentration were noted during periods when subjects were instructed to increase 40Hz, and the opposite during "suppress" periods. No data are presented in the abstract to show that 40Hz varied systematically with instructions, and in view of the inability of subjects in the Ford study to suppress 40Hz it seems possible that Newton's subjects may simply have diverted concentration and effort away from problem solution, attempting with difficulty to suppress 40Hz output as directed. One of several electrode placements was said to have improved cognitive problem-solving performance to a degree "that could not completely be attributed to practice effect alone". Although subjects who were able to increase 40Hz voluntarily showed more of this frequency during problem-solving trials than did subjects who were not successfully trained to emit 40Hz, they did not as a group show superior performance on the problems nor was bidirectional control of EEG during problem-solving shown (if attempted).

There is little evidence that training in ALPHA regulation can affect performance, although a few studies report data somewhat suggestive of such an effect. Jackson (1978) found that in a group of retarded subjects EEG ALPHA suppression was associated with an increase in number and percent correct of arithmetic problems solved, plus diminished head-turning, a behavior incompatible with attention to the problems. Adkins and Murphy (1982) report that subjects trained to decrease left hemispheric dominant EEG frequency did better on a "verbal syntactic task" than groups trained to decrease right-side dominant frequency or fingertip GSR (galvanic skin response), although there were no differences for reaction time or spatial problem solution. No evidence is presented, however, with regard to EEG activity during problem-solving. The authors suggest that the improved verbal performance reflects lowered left hemisphere arousal and an improvement in transcallosal information flow, and that these results imply an effect other than increased speed of transmission, or general relaxation, attention, or concentration. The relatively small size of the left hemisphere effect, and lack of a complementary effect from right hemisphere training (better performance on spatial problems), weakens the import of these results. Earlier, Murphy and Maurek (1976) reported somewhat similar findings, in an attempt to link changes in EEG to differential performance on verbal and spatial tasks.

Several investigators have attempted to observe changes in sensory threshold resulting from self regulation of relevant central nervous system events. Such a phenomenon could, potentially, contribute to enhancement of performance of tasks requiring detection of low amplitude signals. Finley (1984) found that conditioned self regulation of the N14 component of the brain stem auditory evoked response (BAER) lowered sensory thresholds for touch and median nerve stimulation, and concluded that "...conditioning of very early neural events in humans results in altered sensory function". Finley, Kariman and Alberti (1979), however, failed to confirm an earlier finding that learned augmentation of the IV-V component of the BAER led to lowered auditory thresholds, although amplitude and latency effects were observed (the authors point out that a decrease in latency is usually interpreted clinically as reflecting improved hearing). Some further evidence that learned control of sensory evoked responses may affect subjective sensation was found by Rosenfeld, Dowman, Silva, and Heinricher (1984), who observed changes in sensitivity to pain by rats trained to regulate components of somatosensory potentials.

A line of investigation treated fully in several chapters of Elbert, Rockstroh, Birbaumer and Lutzenberger (1984) shows the effects of voluntary control of the slow-rising negative cortical potential (SP) observed during waiting periods subsequent to an alerting stimulus. In the basic laboratory paradigm (Elbert, Birbaumer, Lutzenberger and Rockstroh 1979) a stylized representation of a rocket must be guided toward a target, and is deflected upward or downward by changes in SP. Generally, these investigations indicate that SP negativity is associated with arousal, and positivity with relaxation. Subjects do best in learning to self regulate SP when able to suppress "responses of the muscular, respiratory and cardiovascular systems" in either direction. Moderate increases in negativity have been shown to be associated with faster reaction time (Birbaumer, Elbert, Lutzenberger and Rockstroh 1979), greater speed in solving arithmetic problems (Lutzenberger, Elbert, Rockstroh and Birbaumer 1982), improved signal detection (Lutzenberger, Elbert, Rockstroh, and Birbaurer 1979); positive shifts and large negative shifts have been counterproductive. The authors believe that this effect reflects unspecific preparation (motor and psychological) for cerebral or motor performance, and that the amount of late negativity indicates the quality of preparation. Bauer (1984) reports that spontaneous (not learned) shifts in SP were associated with improved performance on concept identification, paired associate learning, and (only weakly) with incidental learning.

This basic effect, a relationship between SP negativity and cognitive performance, has been seen sufficiently often to promote reasonable confidence in its validity. It is interesting to note that the phenomenon apparently occurs whether subjects are instructed to self-regulate SP during performance test trials (e.g., the signal detection paradigm) or not (arithmetic problems); it is unclear whether subjects were instructed to self regulate during the reaction time trials. Whether improved performance on any given trial reflects increased SP negativity during that trial, or rather ensues from, say, a cumulative effect of previous trials where SP negativity has been achieved, bears, of course, on interpretation of these results and their potential for operational usefulness. More precise data on the degree and phase of voluntarily regulated SP shifts at the actual time of performance and for the second or two preceding it would be helpful. It should be noted also that effects are not always of a magnitude impressive for operational use; for the arithmetic problems, mean response times for SP negative conditions were only 55 ms. lower than for SP positive.

In another study contributing to support of the view that specific behaviors or states may be related to and affected by voluntary regulation of specific brain events, Hauri, Percy, Hellekson, Hartmann and Russ (1982) found that insomnia patients of distinct types responded differentially to EMG and THETA enhancement training vs. sensori-motor rhythm (SMR) training. Those unable to relax while attempting to sleep tended to benefit from the former but not the latter; patients who were able to relax but not sleep tended to benefit from SMR regulation training but not the biofeedback arousal training; with reverse conditions, which resulted from random assignment to groups, some detriment to sleep was noted.

In this clinical study, some data deriving from subjective home sleep logs is at variance with results from data gathered in the sleep laboratory at followup. Nevertheless, the results seem encouraging, since they present another instance of voluntary changes in discrete brain events resulting in differential changes in observable behavior.

While most studies testing the effect of autonomic nervous system self regulation on performance have met with very limited success, potentially useful results have been reported by Hayduk (1979;1980;1982). Consistent with the results obtained by Taub (1977) mentioned earlier, these papers suggest that learned regulation of hand temperature may provide a means for enhancing performance of manual taks in very cold environments through increased dexerity.

Pointing out known decrements in sensitivity, strength, and dexerity, and subjective reports of numbness, stiffness, and pain as skin temperature drops significantly below normal, Hayduk suggests that the effects of these problems may be diminished without the clumsiness and obstruction of efficiency resulting from extrinsic insulation. Subjects were trained with a combination of classical conditioning and biofeedback procedures to vasodilate their fingers and tested under cold conditions in an ABA design. A mean temperature increase of 3.2C was acheived; mean decrease after cessation of voluntary warming was 2.9C.

Measures of manual dexterity, finger dexterity, hand strength, tactile sensitivity and pain were taken. During baseline, performance under cold conditions showed considerable decrement, which was largely reversed during test trials of voluntary hand warming. When subjects ceased warming, performance and comfort deteriorated to baseline cold-temperature levels, "on all measures for all subjects". Some magnitudes of percent improvement during warming were impressive, varying from 12% improvement in hand strength to 49% for finger dexterity; cold pain ratings dropped from 63.3 to 31.7 out of 100. The final report (1982), a followup similar in design to the original study but lacking a return-to-baseline condition, presents almost identical results and demonstrates that the ability to hand-warm voluntarily did not diminish during the year separating the two experiments.

Another use of automomic nervous system biofeedback in the control of physiological events which interfere with performance is found in techniques to control motion sickness. Using a procedure they call "autogenic biofeedback training (AFT)", investigators at NASA (Cowings & Toscano 1982, Toscano & Cowings 1982) have trained subjects to suppress autonomic reactivity elicited by nausegenic stimulation, controlling for susceptibility to motion sickness and for general effects of distracting mental activity. Results, measured as number of rotations in a Coriolis rotational acceleration device subjects could tolerate before, during, and after AFT training, indicated sizeable effects. The experimenters believe that the basis for this result lies in augmentation of normal autonomic adaptation processes which may be lacking or diminished in individuals especially susceptible to motion sickness. Operational tests in NASA vehicles are planned.

CONCLUSIONS

Is biofeedback useful for creating a diffuse response, employable at will (or at least frequently, when needed) that can enhance performance? If so, is the effect sufficiently powerful to make the requisite training cost-effective (Figure 4).

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BIOFEEDBACK FOR PERFORMANCE UNDER STRESS IS USELESS

EFFECTS OF BIOFEEDBACK-INDUCED RELAXATION UPON PERFORMANCE ARE WEAK OR NON-EXISTENT

SOME PROMISE EXISTS IN LEARNED CONTROL OF SPECIFIC INTERNAL EVENTS FOR SPECIFIC PERFORMANCE

Figure 4. Major conclusions.

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Use of a diffuse anti-stress response offers less than sanguine prospects. From the earliest attention to this problem, attempts to provide subjects with a response which can assist them to deal with stress have met with failure consistently. There is little indication that one can learn to lower arousal under stress, or that one can in fact learn any self regulatory technique which can enhance performance under these conditions. It is unfortunate that the work of Harris et al (1973-74) which showed CER suppression through heartrate regulation has never, apparently, been pursued. Perhaps there exists some potential in this finding for a way to elicit a more rapid and effective response to sudden threat.

Results of several studies discussed above suggest that biofeedback can contribute to the training of relaxation, and that lowered arousal when coupled with other techniques (e.g., self-generated imagery, cognitive restructuring) may have an enhancing effect upon athletic performance. Much of this research has been designed and executed in such a way that inference is tenuous, yet there are enough data to warrant further study. Substrate for these observed effects may be increased bodily efficiency (see Benson et al 1978; French 1978;1980, e.g.). This would be consistent with the view that excess and extraneous muscle activity interferes with efficient acquisition of a psychomotor skill. Keeping in mind the effect noted by Sabourin and Rioux (1979), whose "active" subjects (those trained through differential relaxation to produce specific levels of tension) performed better on rotary pursuit than subjects trained only to produce and maintain a lowered level of arousal, it does seem reasonable that optimum levels of arousal or muscular tension are at least somewhat task-specific. Indifference or apathy in the face of threat, or muscular ennervation when heavy physical exertion is required, would be counterproductive - as would maximum tension when playing the violin. Before attempting to rearrange subjects' arousal levels to enhance their performance, one should determine, for the specific performance in question, the proper level toward which to aim.

Obviously, a general ability to prepare internally for environmental demand is an unlearned, intrinsic organismic capability. However, augmenting the effectiveness of this behavior may be possible through training which includes biofeedback. It is likely that if energy expenditures are more closely matched to situational requirements, eliminating extras which are non-contributory and probably in most cases counterproductive, endurance and skill will increase. Application may be especially appropriate in athletics, where sustained high energy output in addition to complex skilled performance is required. Increased metabolic efficiency and enhanced psychomotor control would probably improve such performance.

Can biofeedback be used in the training of specific internal responses tied directly to performance (Figure 5)?

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DEVELOP AND TEST PACKAGE INCLUDING BIOFEEDBACK FOR ENHANCEMENT OF PHYSICAL FITNESS

DEVELOP USE OF SPECIFIC EMG BIOFEEDBACK FOR SPECIFIC MOTOR TASKS

TEST USE OF BIOFEEDBACK FOR MARKSMANSHIP AND TASKS INVOLVING SP SHIFTS

REFINE USE OF FINGER TEMPERATURE BIOFEEDBACK FOR COLD ENVIRONMENTS

STUDY BASIC ISSUES TO REFINE AND INCREASE POWER OF BIOFEEDBACK TECHNIQUES

Figure 5. Major recommendations.

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Here the prospects seem somewhat more promising. When microevents are identified which relate clearly in well-defined ways to measureable performance, biofeedback shows potential for becoming a powerful training method. Studies relating control of excess muscle tension to motor performance, learned augmentation of the cortical readiness potential to cognitive performance, and linking several internal events to marksmanship, suggest that when enough is known about the physiology of performance a strategy offering control of the relevant microevents can assist in learning. The results of Daniels and Landers (1981) in teaching marksmen to regulate breathing and heartrate, and in awareness of the heartrate cycle, resulted in improved shooting. It is likely that the crucial part of this experiment was the initial discovery that these physiological events were related to performance success. Similarly, Morasky et al(s) (1981;1983) first determined that excess muscle tension was detrimental to highest quality musicianship, and Elbert et al (1984) that the readiness potential was related to efficiency of cognitive response; without this specific foreknowledge of relationships between internal events and overt behaviors these successful applications of biofeedback could not have been efficacious.

Taken together, these results suggest that biofeedback may be most effective as a tool for enhancement of performance under circumstances where the target is a particular performance, perhaps even a specific dimension thereof, and the internal substrate is clearly identified. Clearly, the use of biofeedback to elicit general constructs such as states of consciousness or lowered levels of arousal have not so far approached this level of success in measureable enhancement of performance. A remediation approach may be useful; that is, if an internal event which may be related causally to a given performance occurs at a level associated with suboptimal performance, perhaps self regulated changes in that level can enhance the performance. This may have been the case with Jackson's retarded subjects and ALPHA (though it stretches credibility to consider that diminished ALPHA causes poor arithmetic performance). In any event, arbitrarily eliciting changes in supposed internal substrates, in the absence of clear understanding of how their levels vary with performance measures, is likely to lead to frustration.

In summary, the following statements seem justified on the basis of the studies reported here:

o biofeedback has not been shown to be effective for enhancing performance under acute and threatening stress;

obiofeedback may contribute to improved performance through arousal reduction in connection with sports training;

obiofeedback is probably most powerfully used for performance enhancement when an internal event is identified as related to the performance of interest, and that event is currently at a clearly suboptimal level.

Important questions remain to be answered with regard to the precise use of learned controls, once they have been shown to affect performance. Most of the studies discussed above for which positive results have been reported link previous training to improved performance; it is largely unclear, though perhaps assumed, that when performance is tested, subjects are actually self regulating the internal event for which they were trained. Careful attention to what takes place precisely at the time of response would improve understanding of the amplitude, sequence, and timing of the internal substrates necessary for optimum results. Persistence and generality (see Finley 1984, on specificity of effect in shaping components of the BAER) are matters of interest, as well. Birbaumer, Elbert, Rockstroh, and Lutzenberger (1981) point out that their subjects were able to self regulate SP during test trials without reinforcement, but it is not clear that this effect can be expected to last more than a few hours. Once trained in, say, amplyfing the readiness potential for a particular task, has a subject been taught a general technique good for a variety of uses? Is such a subject, in other words, better able to concentrate? Or is the effect task-specific - and how frequently will retraining be required?

These and other implications for further research need attention. If biofeedback of specific events can be thus used for better performance, an enormous array of possibilities opens.

RECOMMENDATIONS

1. Develop a training program for physical competence incorporating several facets including biofeedback. Such a program could comprise, in addition to biofeedback, imagery, attitude development through cognitive restructuring, and desensitization to anxiety-provoking stimuli. For this purpose, biofeedback would be employed to promote control of bodily tension, and research would be needed to determine optimum levels of tension for specific purposes. Clearly, effects of biofeedback alone would not be measureable when evaluating the results of such comprehensive training. This is probably not important, since sufficient evidence exists to suggest that similar activities promote success in athletics, and subsequent refinement would provide information about the value of its various components. The primary initial task for Army scientists would be to adapt such training for the physical aspects of military fitness and combat readiness.

2. Undertake a program of research to test and refine the proposition that execss bodily tension interferes with the acquisition and performance of complex psychomotor tasks. Positive findings could have important implications for training in many military activities and could ultimately result in more rapid learning and higher levels of skills attained.

3. Select at least two specific performance areas relevant to military needs for which some evidence exists linking biofeedback to improvement, and attempt to devise a feasible use of biofeedback training for this prupose. Two suggested areas are:

marksmanship(for awareness of heartrate cycle, control of breathing, and fine muscle control) and

signal response and detection (for control of cortical readiness potential to enhance rapidity and, perhaps, accuracy of response).

4. Attempt demonstration for operational use of voluntary hand warming for increased manual dexterity in cold environments. Subjects should be trained using Hayduk's (1980) method.

5. Perform a series of simple studies to determine the validity of performance enhancement through learned suppression of a CER. This phenomenon, if sufficiently robust, appears the only path of any promise toward development of an effective anti-stress response.

6. Consider exploratory research aimed ultimately at assisting personnel to lower sensory thresholds and increase and maintain attention, through self regulation of specific components of evoked responses and slow cortical potentials.

7. If results from some of the above efforts appear promising, undertake research to answer such questions as:

should subjects consciously attempt to self regulate while performing?

how well do various types of biofeedback training generalize to other tasks (see Finley 1984)?

how well does performance enhancement persist without extrinsic reinforcement?

how important for enhancement of performance is the magnitude of the regulated effect?

These studies would require substantial financial support and several years of effort, for evaluation of the general proposition that biofeedback can be a useful training tool for Army purposes. As Stamm (1984) points out with regard to his own findings, "The goal of utilizing SP events for mediation of human behavioral and cognitive deficiencies remains remote"; this may be true as well for other anticipated uses of biofeedback to enhance other sorts of performance.

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