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The presence of residual muscular tension has been implicated as a detrimental influence on the performance and learning of motor skills. A method for reducing muscular tension has been provided by the recent advent of biofeedback training. Thirty young adult males were subjected to tests of stabilometer balancing skill and pursuit-rotor tracking skill, which represented gross and fine motor activity respectively. Following pre-tests, the subjects were ranked by performance scores and divided into identical triplicates. Two experimental groups and a control group were formed when one subject of each triplicate was assigned to each group. The two experimental groups were trained by electromyographic biofeedback techniques to reduce muscular tension in the frontalis muscles. After a total of three hours of training for the experimental subjects, all subjects were re-evaluated on the same motor skill tasks. One experimental group received electromyographic feedback during the post-tests. Analysis of variance groups by trials, analysis of variance of difference means, and t tests of scores representing performance and tension suggested that: a) electromyographic biofeedback training significantly (1) reduces tension induced by novel motor skill learning and (2) improves motor performance of fine and gross motor skills; b) transfer of tension-control training of a general nature facilitates learning and performance more than direct biofeedback during performance; and c) a higher tension level is necessary for performance of fine motor tasks as tension correlates positively with performance. Residual tension reduction and control were particularly facilitated by electromyograph biofeedback methods, which may have profound implications for the management of stress in a variety of situations.

Electromyographic Biofeedback for Tension Control During Fine and Gross Motor Skill Acquisition

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CHAPTER I

INTRODUCTION

The physically and mentally handicapped and the motor unskilled may all demonstrate various degrees of abnormal or excessive motor activity during performances of fine or gross motor skills. Participants in a variety of sports events which require co-ordinated movements and precise control for successful execution are frustrated and hampered by excessive muscular tension. On the other hand, the superior athlete thrives on a conservation of muscular tension, which results in a synchrony of flowing movement. The relatively unskilled performer is an inefficient co-ordinator of the muscular contractions which produce synchronous movement. This person's efforts are wasteful, one contraction resisting another, as all conscious effort strives to achieve the orthodox form. Sensory information from this person's muscles is confusing in its abundance, and progress is slow and unrewarding. How may the learner reduce residual tension that is clearly detrimental to motor performance?

Electromyographic biofeedback may be thought of as "augmented" feedback information or kinesthetic awareness. Muscle tension provides the body with natural proprioception which may be trained through biofeedback to provide a heightened sensitivity to minute muscle contractions. The electromyograph is an electronic instrument which directly measures muscle tension. Training such as this can provide the trainee with a means to reduce unwanted tension, and perhaps maintain a low tension level during the performance of a task normally limited by excess tension, induced by the very nature of the task. A person receiving biofeedback through an electromyograph during practice of a task is provided an immediate measure of his tension responses to his learning behaviour, which should prove instrumental in optimizing skill learning.

Significance of the Study

Many researchers have been involved in the problem of inducing tension and studying its effects on motor learning. Relatively few have investigated the effect of relaxation on gross human movement. Two major studies, those of Benson (1958) and Paben and Rosentsweigh (1971), have demonstrated that performing and learning new motor skills were facilitated most in subjects who were "taught how to relax". Relaxation training and instructor feedback in these two studies were not confined to pre-test practice or during testing itself, but were continually provided for the subjects while they practiced and performed.

Training methods in these earlier studies were not of the direct feedback nature proposed for this study. An extensive review of the literature indicates that no research of the type proposed in this report has been conducted.

Purpose of the Study

The purpose of this study was to analyse the effects of electromyographic biofeedback for tension control on the acquisition of fine and gross motor skills. Excessive tension is detrimental to motor performance. Recent research has established that the electromyograph, by providing information about muscle tension that the subject cannot normally perceive, can supplement normal proprioceptive mechanisms until they become sensitized sufficiently to provide voluntary control over tension. A reasonable assumption can be made, therefore, that electromyographic biofeedback may be instrumental in reducing tension to a desirable level which may enhance motor performance. The intent of this investigation was to train individuals to reduce general muscular tension and evaluate the effects of this training upon two extremely varied motor activities. A stabilometer balancing test, which measures total body moving balance on a tilting platform, was selected to represent gross motor activity. The fine motor task involved precise hand-eye co-ordination with very little movement, and was performed on a pursuit-rotor tracking machine.

Numerous research questions were of concern in this investigation:

1. Does electromyographic biofeedback training for tension control produce higher motor performance scores in a gross motor skill test such as the stabilometer dynamic balance test, which evokes high tension levels in unskilled performers?
2. Does electromyographic biofeedback training for tension control produce higher motor performance scores in a fine motor skill test such as the pursuit-rotor tracking test, which evokes high levels of tension in unskilled performers?
3. Does electromyographic auditory biofeedback provided during performance facilitate learning and/or performance of fine and gross motor activities?
4. Do subjects trained in tension control respond similarly to fine and gross motor activities which evoke similarly high tension levels.
5. What relationship exists between the performance score of a fine and/or gross motor test and the tension levels manifested during performance?
6. When electromyographic biofeedback training for tension control is used to reduce general muscular tension with no specific training for a particular fine or gross motor activity,

how much transfer of tension control training occurs during the performance of a specific activity?

7. Since some learning should occur between one performance and the next of a novel motor activity, what part of that learning can be attributed to normal learning progress, and what part is the direct outcome of electromyographic biofeedback training for tension control?

On the basis of these research questions, the following null hypotheses were developed and tested:

Hypothesis one: No significant difference exists between responses of subjects trained in tension control and untrained subjects to a stabilometer balancing task.

Hypothesis two: No significant difference exists between responses of subjects trained in tension control and untrained subjects to a pursuit-rotor tracking task.

Hypothesis three: No significant difference exists between responses of subjects trained in tension control and untrained subjects to a stabilometer balancing task when the trained subjects were provided auditory biofeedback during post-training performance.

Hypothesis four: No significant difference exists between responses of subjects trained in tension control and untrained subjects to a pursuit-rotor tracking task when the trained subjects were provided auditory biofeedback during post-training performance.

Hypothesis five: No significant difference exists between responses of subjects to the stabilometer balancing task between pre-testing and post-testing of this event.

Hypothesis six: No significant difference exists between responses of subjects to the pursuit-rotor tracking task between pre-testing and post-testing of this event.

Hypothesis seven: No significant difference exists between responses of the tension control trained subjects who received feedback during testing and those trained subjects who received no feedback during testing on the stabilometer balancing task.

Hypothesis eight: No significant difference exists between responses of the tension control trained subjects who received feedback during testing and those trained subjects who received no feedback during testing on the pursuit-rotor tracking task.

Responses of the subjects were tested with respect to two criterion measures. One measure evaluated the performance and learning of the subjects. The second estimated the tension induced by the task and therefore evaluated the changes in tension with performance. Correlations between performance and estimated tension criterion measures were computed.

Delimitations and Limitations

Restrictions on the nature and scope of this study were imposed to effect a workable research problem. Thirty caucasian male college student volunteers who demonstrated normal motor ability served as subjects. Many were active in intramural athletics but none competed at the varsity level.

When human subjects perform in scientific experiments which require maximal voluntary responses, serious limitations are inevitable. Learning factors are a complex array of variables which provide countless possibilities for behavioural outcome. Every conceivable precaution was taken to prevent motivational factors from affecting performance. Tension levels, which are extremely sensitive to intrinsic and extrinsic motivation, were monitored constantly throughout performance. Instruction on methods and procedures for testing was standardized by a synchronized slide-tape presentation. Clarification of this information only was offered in response to questions posed by the subjects. Every effort was made to provide for the comfort of the subjects. Despite this degree of experimental control, however, the nature of the specific tasks, the criterion instruments, the number of trials and the length of the trial intervals impose limits upon the interpretation of the data. Academic pressures are prone to fluctuate throughout the course of a five week interval. Although no quantitative data could be established, tension induced by academic stress or emotional stress was probably the most limiting factor of the investigation.

CHAPTER II

REVIEW OF RELATED LITERATURE

Orientation

Biofeedback, as the term applies in psychophysiological circles today, has a bewildering variety of possible applications. The term refers to those techniques commonly involving electronic instrumentation which give the subject immediate and continuous information via amplified signals of bodily function of which he or she is not normally conscious. Popular modes of biofeedback training in use world wide include systems monitoring blood pressure and other cardiovascular parameters, brain-wave activity, skin temperature, or muscle tension.

Muscle tension is measured in electromyography, made possible by the reception of electrical impulses within the muscle (muscle action potential) by sensitive recording electrodes. This signal is amplified several thousand times to produce audible wavelengths and drive a galvanometer which records muscle tension in microvolts. A premise of this investigation is that such a signal provided for the subjects during tension control training and performance of tension-inducing tasks will provide reinforcement for learning, and assist the subjects in eliminating excess tension that serves to reduce the efficiency of motor learning and performance.

This review of the literature has been designed to present logically the physiological and psychological principles of motor skill learning and performance, and relate them to electromyographic biofeedback manifestations in tension control training. The criterion motor performance tests in this research investigation have been discussed with respect to their specific implications in the context of this review. Natural biological feedback systems of the body are the basis of proprioception, and biofeedback in the context of this research represents augmented proprioception with respect to muscle tension.

Neurophysiological Bases of Proprioception

During the late 1920's and early 1930's the discovery of electronic amplifying and recording devices opened a new dimension of physiological research. The pioneer work in proprioception was carried out by Adrian and Zotterman (1936) and Matthews (1931, 1933). Adrian developed the technique of recording from single sensory nerve endings. Matthews, however, applied the technique to recording from muscle spindles in frogs and mammals, and advanced the theory of muscle spindle response to stretch and contraction. Matthews' experiments also provided detailed information concerning the junction of the Golgi tendon organs. Since the 1930's continuing sophistication of electronic recording devices has enabled more accurate descriptions and further discoveries of physiological functions involved in proprioception.

Muscle Spindles

The muscle spindle receptors are interspersed between the ordinary orextrafusal muscle fibres. The spindle consists of between two and ten intrafusal muscle fibres which may be thought of as a single functional unit. The muscle spindle is essentially a specialized form of muscle fibre containing contractile elements as well as the receptor organs. Each intrafusal fibre is distinguished by three major sections; the contractile elements are located proximally and distally in the so-called polar regions. Between these sections lies the equitorial region. The equitorial region itself is separated into three sub-sections. In the centre lies the nuclear bag, which is a slight swelling of the fibre containing a lymph filled capsule. The nuclear bag is separated from the polar regions by the myotube or transitional section. The nuclear bag contains receptor end-organs and the lymph serves as a protection from mechanical pressures. This ensures that the stimulus for the end organs is changes of tension along their length.

The endings found in the nuclear bag are known as primary endings. Secondary endings are found in the myotube region. These endings are sometimes referred to as annulo-spiral endings and flower spray endings respectively. Both sets of endings respond to the stretching of the muscle in which they are found. However, some slight functional differences between the two sets of endings exist.

These differences are probably due to differences in location; the secondary endings are found in myotube sections which have some contractile elements, whereas the primary endings are found within the nuclear bag (Granit, 1955). Spindle firing is elicited during many kinds of stretch, the primary endings apparently having a much lower threshold than the secondary. The primary endings also show a low frequency resting discharge. During linear stretch the primary ends increase their rate of discharge markedly whereas the discharge of the secondary endings increases little above the level found in maintained stretch (Cooper, 1961). Perhaps the most distinct difference between the patterns of firing of the two sets of endings is found in their reaction to the release of stretch. The primary endings cease firing immediately, but the secondary endings maintain a low level of discharge during the release phase.

Muscle spindles are arranged 'in parallel' with the extrafusal muscle fibres. When the extrafusal muscle contracts the muscle spindle receptors cease firing. This pause in the discharge from the muscle spindle receptors occurs particularly in isotonic contraction, and it continues until contraction of the intrafusal muscle fibre realigns the spindle in terms of length with the extrafusal muscle fibres surrounding it. Usually, there is also a pause in isometric contraction due to the take up of elasticity in the muscles and tendons releasing tension on the muscle spindle. If isometric contraction continues after the initial realignment of spindle and extrafusal fibre has occurred, the spindle firing will continue (Howard and Templeton, 1966).

Adaptation is rapid for the muscle spindles and for this reason the maximum discharge depends not only on the amount of tension but also on the rate with which stretch occurs (Howard, 1966).

Afferents from the spindles feed into the dorsal roots of the spinal cord and project up the spinal cord to the cerebellum. Mountcastle (1957) has demonstrated that stimulation of the muscle spindles does not produce any response in the somaesthetic area of the cortex and it is therefore considered unlikely that a direct link exists between the spindles and levels higher than the cerebellum. The muscle spindle afferents are also involved in monosynaptic reflexes. These are the simplest form of sensory-motor relationship. The axon from the dorsal root terminates directly on the second neuron of the feedback loop, the ventral horn motor cell. This reflexive function of muscle spindle afferents is relatively uncommon in higher animals, only forming part of the postural mechanisms and influencing the maintenance of body tonus.

Apart from the simple feedback loop involved in reflexive control, a further feedback loop, of which the muscle spindle afferents form a part, exists. This has become known as the gamma efferent feedback loop. (The terms gamma and alpha fibres are based on the classificatory system of Erlanger and Gasser (1937) relying on conduction velocities). The muscle spindles are innervated by gamma fibres, whose efferent discharge causes contraction in the polar regions of the intrafusal muscle fibres. The result is a change in tension in the equatorial region of the fibre and therefore an alteration in afferent activity. The afferent activity, in turn, affects the alpha neurons which stimulate contraction of the extrafusal muscle.

Eldred, Granit and Merton (1953), on the basis of this evidence, suggested two entirely different ways for contraction of the extrafusal muscles to occur. Firstly, contraction may occur as a result of direct alpha stimulation or, secondly, through the gamma fibre system. The authors emphasized that the initiation of contraction via the gamma system has the advantage of higher levels of feedback control, but this may produce delays in contraction because of conduction time. Howard and Templeton (1966) speculated that the direct pathway (i.e., alpha stimulation) may be used for 'ballistic' or well-practiced movements and that the indirect pathway may be reserved for exploratory or tentative movements.

A complete analysis of the gamma fibre feedback loop is not developed and some controversy still remains concerning the role of this system. The feedback loop appears to be mediated through the anterior lobe of the cerebellum and the diencephalic reticular formation. The loop is, however, very complex. Each muscle spindle receives several gamma efferents and each gamma efferent has branches to several spindles.

One further aspect of this complexity is illustrated by a phenomenon demonstrated by Gellhorn (1948) and Brainin (1957). They found a feedback influence not only upon the extrafusal muscle in which the spindle is found, but also upon the muscle's antagonist. Their results differed in terms of the form of this influence and to date no generalized conclusion has been reached.

Muscle spindles appear to operate at two distinct levels. At one level they are concerned with providing information concerning stretch occurring within the muscle. At another level they participate in a feedback system involving contraction. Grossman (1967) suggested that the latter function may often be dominant and even override the normal suppression of spindle activity which occurs during the contraction of the extrafusal muscle.

Golgi Tendon Organs

The Golgi tendon organs are typically found at the insertion of the tendons into the muscle. According to Baker (1948), it is probable that these organs exist frequently at the insertion of the muscle spindles themselves.

The functioning of the Golgi tendon organs is similar to that of the muscle spindle receptors and the two systems co-operate closely.

Some important differences in the functional properties of these systems are apparent however. The Golgi tendon organs are responsive to the degree of tension within the muscle, but they are responsive to the total tension whether this is produced by stretch or by contraction. Tendon organs therefore discharge during that period of time during contraction when the spindles cease firing. Whereas the muscle spindles appear to function in 'parallel' with the extrafusal muscle, the Golgi tendon organs operate as though they were in 'series' with the muscle.

The Golgi tendon organs show no resting discharge and generally have a much higher threshold to tension than the muscle spindle receptors. The tendon organs also appear to adapt less rapidly. For this reason, in terms of total transmission from the muscle, the proportion of discharge is greatest from the muscle spindles at low levels of tension produced by stretch, but this proportion decreases as the tension increases.

The afferent pathways from the tendon organs are similar to the afferents from the muscle spindles. They enter the spinal cord by way of the dorsal roots and there initiate monosynaptic reflexes. Whereas the muscle spindles initiate stretch reflexes, the tendon organs are concerned in the production of inhibitory reflexes. In a long series of experiments on reflexive behaviour, Granit and co-workers (1955) demonstrated that the action of the spindles serves to facilitate the contraction of the muscle within which they are found, and to inhibit that muscle's antagonist. The Golgi tendon organs, on the other hand, were found to inhibit the muscle upon the tendon of which they were located, and to facilitate the action of the muscle's antagonist. Apparently because of the higher thresholds of the tendon organs, inhibition does not appear until higher levels of stretch are achieved. With severe distortion of the limb the inhibition effect may override facilitation causing sudden lengthening in the extrafusal muscle. In simplified form the system appears to work in the following way. Passive stretch causes reflex facilitation of the contraction of the muscle. This is mediated through the muscle spindle afferents. With increasing tension the higher threshold tendon organs begin to discharge causing reflexive inhibition of the contraction. If the distortion of the muscle continues this inhibition of contraction may become dominant and sudden lengthening occurs.

The tendon organ afferents also project up the spinal cord to the cerebellum. A direct link to the cortex appears improbable (Oscarsson 1966). Also, the tendon receptors are not likely to directly affect the gamma efferent system (Hunt and Paintal, 1958).

Apart from the role of the tendon organs in reflex control of muscles, therefore, their contribution to total proprioception information probably is restricted to providing additional monitoring of tension changes which are recorded and integrated with other sensory information at the cerebellar level.

Joint Receptors

Contained within the joints are three distinct forms of receptors. These receptors being isolated from the muscles are not sensitive to changes in muscular tension. Their stimulus appears to be movement around the joint and joint position. In functional terms, differences between the three types of receptors exist. Located within the ligaments, which bind the joint and limit its movement, are found endings similar to the tendon organs. The receptors in the ligament are therefore known as Golgi-type endings or free-endings. Within the joint capsule itself, particularly in the connective tissue, the receptors are known as spray-type endings (sometimes called Ruffini-type endings because of their similarity to the receptors in the skin). Also found within the joint capsule are receptors termed pacinian or paciniform corpuscles. Still some doubt exists concerning the precise function of all the receptors of the joint although some informed speculation has been possible. To a large extent, the evidence seems to point to a distinction between those receptors signalling position and those receptors which provide information concerning movement (Gardner, 1950; Boyd, 1954).

The spray-endings and the Golgi-type endings appear to signal position, whereas the pacinian corpuscles register movement. The position receptors have an extraordinary flexibility of discharge. They are generally slowly adapting and appear to discharge at specific joint angles without reference to the direction of movement. A single receptor may adapt at different rates for different joint angles and differences may exist in the range over which receptors are sensitive. That is, some receptors may fire at any joint angle, others may be active for small joint angles and others at large joint angles (Berry, Karl and Hinsey, 1950).

The pacinian corpuscles produce very different discharge patterns. These movement receptors adapt very rapidly and their response is independent of joint angle. These receptors have as their stimuli the velocity, acceleration and direction of limb movement. Thus some receptors may respond only to a specific direction of movement. For other receptors quantitative changes in frequency of discharge dependent upon the velocity of movement are likely to occur (Smith, 1969).

The afferents from the joint receptors project via the dorsal root into the lemniscal system, the thalamus and so to the sensory cortex. The specific route of the afferent fibres of joint receptors is fairly straight forward. From the dorsal root the fibres form part of the dorsal funiculi. At the level of the brainstem they synapse with the nuclei cuneatus and gracilis. The secondary neurons form part of the medial lemniscal system. A second synapse occurs in the thalamus and the third stage or tertiary neurons project to the sensorimotor cortex. At the level of the thalamus, Mountcastle, Poggio and Werner (1963) noted a high degree of neural integration and convergence. This suggests that a summarizing and encoding process is probably occurring at this level. Perception of movement characteristics, therefore, may be based on less than direct information from the receptors. Mountcastle (1957) demonstrated that mechanical stimulation of single receptors does produce a response in the cortex, and similarly, cortical response is found from electrical stimulation of the joint afferents (Gardner and Haddad, 1953).

Perception involves the active participation of the individual to his interpretation of the stimuli received. Thus, temporary states of the organism, e.g., fatigue, drugs, etc., are likely to change perception even though the physical characteristics of the afferent input may be the same. Also, the way in which information from the receptors is organized and interpreted will depend on previous experience and familiarity with the movements in question. Perhaps of even greater importance is the question of attention. The same individual may perceive or fail to perceive identical stimuli on two different occasions because of attention or inattention at these times. Generalizations concerning the nature of perception of movement are impossible on the basis of the type of afferent nerve impulses.

Vestibular System

Situated within the inner ear are sense organs known collectively as the vestibular apparatus or labyrinth. The utricles are sensitive to all forms of linear acceleration. The vestibular canals form a three part system, the integration of information from all canals providing information concerning the direction of rotary head movement as well as accelerative information. Movements of the head which occur within the plane of a specific canal causes discharge via the sensory-end organs located within the sensory ciliated epithelium of the canal.

The afferent pathways of the vestibular system are highly complex. Axons from the vestibular apparatus form a part of the eight or auditory nerve and project to the brainstem in close association with the cochlear branch and enter the medulla. Many of the fibres terminate in the four vestibular nuclei of the brainstem, which are the source for important ascending and descending fibres. The majority of the projections from the vestibular nuclei are involved in the mediation of vestibulo related reflexes. Thus one set of fibres originating in the spinal nucleus descends the spinal column in the lateral vestibulo spinal tract, terminating in the motor neuron pools. Similarly, descending fibres from the medial, lateral and spinal nuclei pass through the medial vestibulo spinal tract to terminate in motor neuron pools. Both these sets of fibres are thought to mediate vestibulospinal reflexes. Fibres also pass from the nuclei to the oculomotor centres of the brainstem and produce the vestibular nystagmus reflex. A direct pathway leads from the vestibular nuclei to various parts of the cerebellum. The vestibulo reticular pathways from the superior and medial nuclei distribute widely through the bulbar and pontine reticular formation. Most recently projections from the vestibular nuclei to the cerebral cortex have been found. A distribution of fibres to some thalamic nuclei project to the superior temporal lobe and premotor areas of the frontal lobe (Gernandt, 1964).

Functionally therefore, the vestibular mechanisms serve several different roles. Their principal phylogenetic task has been in the production of body righting reflexes. The influence of vestibular reflex control may be demonstrated in human neonates, but the development of voluntary control soon supercedes this reflexive activity.

The vestibular apparatus also contributes at two other levels. Firstly, vestibular information is integrated with information from other systems operating at the unconscious level, e.g., the muscular and tendon afferent sources. Secondly, there is the contribution of the vestibular mechanisms to the total perception of movement, achieved via the connection of the vestibular apparatus to the cortex.

The Cerebellum

Many of the propioceptive feedback loops involve the participation of the cerebellum. The muscle spindles, the tendon organs and the vestibular mechanisms all have direct connection with this organ.

Traditionally the cerebellum has been ascribed the role of co-ordinating centre for motor responses. Particularly the cerebellum was thought to govern 'automatic' responses. However, evidence is growing which supports influence of the cerebellum on all forms of voluntary as well as automatic movements.

In summary, the cerebellum receives afferents from all other sensory modalities as well as proprioceptive and vestibular afferents. The anterior lobe is reciprocally connected with somatosensory area I of the cerebral cortex. The posterior lobe is reciprocally connected with somatosensory area II. The motor area of the cerebral cortex and the anterior lobe are also reciprocally connected.

The cerebellum is therefore ideally placed for co-ordinating information arising both from the extraceptors and proprioceptors. Similarly the close connection with the cerebral cortex allows for a measure of control in the performance of movements and the integration of cortical movement impulses with the afferent information concerning the effect or effectiveness of these impulses (Ruch, 1965).

The reciprocal relationship between the cerebellum and cerebral cortex, the efferent discharge from the cerebellum by means of axons from the Purkinje cells, and the projections from these cells which terminate in either the cerebellar nuclei or the lateral vestibular nucleus constitute three interdependent feedback loops. The first begins with the sensory receptors, proceeds to the cerebellum and then to the motor cortex. Action in the motor cortex will therefore affect the ongoing movement causing a change in receptor activity and thus completing the feedback loop. A second feedback loop provides information from the integration centres within the cerebellum to the motor cortex. Efferents from the motor cortex pass not only down to the muscles involved in the movement but also, by way of the pontine nuclei and principal inferior olive, back to the cortex. Finally, a feedback circuit operates between the cerebellum and the receptor systems. The cerebellum receives information from the peripheral receptors and, after preliminary integration, the impulses are directed via the red nucleus back into the rubrospinal tract of the spinal cord, thereby causing changes to occur in the evolving movement.

On the basis of these three feedback loops, speculation is possible on the centres for secondary integration of impulses. Primary integration occurs at the level of the cerebellum. In the two feedback loops involving the cerebral cortex further and more complete integration in the motor cortex is likely to occur before the transmission of new impulses to the muscles producing movement. The secondary integration for the final feedback loop between the cerebellum and the receptor systems is less easily determined. Eccles (1967) maintained that this is achieved by integration actually occurring within the spinal cord and in 'the evolving movement itself'. Although Eccles claimed that this concept was novel, a similar point was made by Paillard (1960).

Howard and Templeton (1966) proclaimed that feedback mechanisms are inherently unstable. Any system which operates through error control is likely to reveal oscillatory tendencies and allow overshooting to take place. If the feedback systems described above were the only means by which control was exerted, movement would not be smooth or accurate and the tendency to overshoot targets would exist. One function of the cerebellum may therefore be as a feedback stabilizing mechanism (Ruch, 1951, 1965). Tendency to oscillate or overshoot may be further prevented by means of the cerebello-cerebral feedback loop. Ruch (1965) suggested that the motor cortex is incapable of planning movements in time, since impulses cannot be stored and discharged after some delay. However, if impulses from the motor cortex were discharged into the feedback loop involving the cerebellum, programming in time might be possible.

On the basis of experimental evidence, Gibbs (1954) postulated an alternative method by which overshooting of movements may be prevented. His suggestion was based on the possibility of rate control of movement. The extent of movement may be estimated, Gibbs maintained, by the integration of a known rate of movement over a known period of time. In order for this type of control to be possible, intermittent estimates of the position reached during movement are necessary. This suggestion offers a visible alternative in the solution to the problem of overshooting.

The Reticular Formation

The reticular formation merits attention because of its role within feedback mechanisms involving proprioception. The anatomical position and structure of the formation make it uniquely suitable for performing additional integrative functions of sensory and motor impulses. By means of a tonic inhibition mechanism, the formation is capable of decreasing the apparent sensitivity of sensory mechanisms. Decreases in this inhibitory function result in an apparent facilitating effect. In terms of proprioceptive information which is transmitted to the cortex, the role of the reticular formation is critical for perception to result from these impulses. Facilitation may cause increased sensitivity to this information and render perception less probable. A reciprocal connection also exists between the reticular formation and the cortex. The ascending reticular activating system produces a generalized arousing effect upon the cortex and the cortex is capable of stimulating the reticular formation. In this way cortical control over level of arousal or over the facilitation of particular sensory inputs may be the physiological basis of selective attention (Grossman, 1967).

Increasingly the function of specific areas of the formation are being delimited. Participation of the reticular formation is now known not to be restricted to feedback circuits involving the cortex. Granit and Kaada (1952) noted that the gamma efferent feedback loop is directly influenced by the formation. Reticular activity appears to adjust the tension of the intrafusal muscle fibres through stimulation of the gamma system. Since the changes which occur in the intrafusal fibres have little or no effect on the tension within the total muscle, the result is a bias in the spindle's afferent activity. Also, since Moruzzi (1950) has established that the cerebellum has an inhibitory or facilitating influence upon the reticular formation, the formation evidently exerts an influence upon the proprioceptive feedback loops which do not have direct connection with the cortex.

Apart from a 'motor' influence through the gamma efferent system, the formation is also involved in modifying spinal reflexes. These descending influences are thought to be both facilitatory and inhibitory (Sprague and Chambers, 1954). Thus, the reticular formation serves as a modifying system for both afferent and efferent sides of the proprioceptive feedback circuits. Since the formation has a similar influence on all sensory systems, its integrative functions in intersensory terms may be paralleled in importance only by the cerebellum and cortex.

Proprioception and Performance

The phenomenon of proprioceptive feedback is associated with the performance of all physical tasks. Not all of this feedback may be consciously appreciated. However, evidence presented earlier suggests that, for a large range of human movement, proprioceptive stimuli may be appreciated by the performer. In some respects man appears to be highly sensitive to these stimuli, but the multi-dimensional character of proprioception defies generalization. Since man is capable of detecting movement at a conscious level with some degree of accuracy, a superficial conclusion might be that proprioception is highly relevant to performance. Similarly, the conclusion may be extended to suggest that the greater the degree of sensitivity, the more accurate the movement characteristics will be. That is, if proprioceptive feedback is relevant to skilled movement, the greater the proprioceptive sensitivity, the higher the level of skill with other aspects constant. This proposition has been the basis of much experimental research and the conclusion has found support in many studies.

Several attempts have been made to relate tests of the totality of proprioception to physical performance. Unfortunately the quality of these tests do not allow very significant conclusions to be drawn.

The discrimination between athletes and non-athletes as a measure of validation for tests of proprioception has been used to indicate that proprioceptive sensitivity is an ability relevant to athletic performance (Kerr and Weinlund, 1933 and Wiebe, 1954). Other experiments have shown similar levels of importance for proprioception in gross motor skill activities. Phillips (1941) and Phillips and Summers (1954) used a single measure of proprioceptive sensitivity, arm positioning ability, and found a significant relationship between this measure and performance at certain stages in gross motor skill activity.

Proprioception and Learning

The distinction between learning and performance can be made at several different levels. Most frequently learning has been defined in terms of relatively permanent changes in behaviour, whereas performance is regarded as behaviour which may result from learning, but also be influenced by factors other than learning. For example, fatigue, drugs and other temporary states of the organism are usually viewed as affecting performance rather than learning. However, as Gagne and Fleishman (1959), and Bugelski (1956) have established, learning is essentially an internal neural change, and its occurrence must be inferred from performance. Learning, therefore, is a factor, but not the only factor, in determining level of performance. Behaviour which is a product of genetic programming and uninfluenced by environmental factors cannot be included in the definition of learning. Reflexes are unlearned behaviours which depend primarily on the structure of the nervous system and the physiochemical make up of the organism rather than being the product of learning.

Proprioception and Learning Theory

For some learning theorists, proprioception has been accorded a major role. Notably, S-R theorists who have accounted for learning on the basis of peripheral intermediaries, have devoted attention to the phenomenon of proprioception (Hilgard and Bower, 1966). For example, proprioceptive information is an essential component of the learning theory of Guthrie (1952), whose work has considerable bearing upon the issue of contiguity versus reinforcement mentioned by Hilgard and Bower (1966). Guthrie specified that modification of behaviour occurs because stimuli come to elicit a response which they had previously not produced, due to the simultaneous occurrence of those stimuli with a response. Obviously, this view of learning applies very well to classical conditioning where an unconditioned stimulus elicits an involuntary unconditioned response and repeated pairings of a conditioned stimulus with the unconditioned stimulus eventually result in a conditioned response to the conditioned stimulus alone. In later revisions of his theory, Guthrie (1959) suggested that not only must stimuli and responses be associated contiguously in order for learning to occur, but the organism must be paying attention to the particular stimuli. That is, the organism must notice the stimulus pattern before the association occurs. Guthrie's research demonstrated the significance of selective attention to both proprioceptive and extraceptive cues in the learning process.

The role of proprioception in learning theory has not been exclusively the province of the contiguity theorists. Hull (1952) emphasized the incremental nature of learning and stressed the role of reinforcement in the learning process. The connectionist view of Hull does not differ significantly in this narrow context from Guthrie's position. Both regard proprioceptive stimuli as having the potential to become linked with overt responding.

Greater refinement was made to Hull's view of proprioceptive influence in the work of Mowrer (1947, 1960). Although Mowrer made considerable use of feedback mechanisms in his theory of learning, he incorporated evidence concerning feedback into a traditional learning theory approach. The concept of feedback has proved so compelling that a completely new approach to learning theories has found its basis in feedback concepts. The application of cybernetic principles to learning has received its major impetus from Smith (1962, 1966). Smith's analyses of the effects of delayed and distorted feedback have led him to far different conclusions from those of Mowrer, and in fact compared with any traditional S-R theorist. Like Mowrer, the majority of S-R theorists have accorded feedback reinforcing properties of various kinds, assuming that feedback gives both information and knowledge of results which may also have rewarding properties. Smith condemned this viewpoint and suggested that many of the problems of learning theories may be solved by abandoning theories based on S-R connections and the concept of reinforcement. For example, he claimed that differences between categories of learning, such as classical or instrumental conditioning, verbal learning, problem solving and motor learning are necessary categorizations only because of the inadequacy of association or reinforcement learning models.

> "From a cybernetic point of view, the different forms or variations in learning reflect differences in patterns of feedback control which the animal or human subject can utilize in a particular learning situation. . . . For this view, the different types of learning result from variations in the modes, conditions, and transformations of feedback stimuli from postural, transport, manipulative, and receptor movements involved in different learning situations." (Smith 1966)

Within learning as a whole, Smith considered proprioceptive feedback valuable as one source in a multidimensional feedback array.

Adams (1968, 1971) reviewed the traditional S-R associationist views and came to similar conclusions as Smith (1966). Adams was particularly concerned with proprioception, and proposed a "closed loop" theory of motor learning in which he stressed that feedback from a response does not act simply as a stimulus for a subsequent response;

but is compared with a reference mechanism to a desired value of feedback. Discrepancies between feedback and the reference value become the source of error correction.

Changes in the Importance of Proprioception during Learning

In 1964, Fitts criticized many of the servo and control system models of performance on the grounds that they conveyed a static view of the processes involved in skill. He stated that a model which does not change its characteristics as a function of experience fails to describe one of the most fundamental aspects of skill. Performance changes through learning are not simply quantitative but depend also upon qualitative changes. The process of skill learning is dynamic and a model which does not reflect the adaptive nature of the learning process cannot be an adequate description. By investigation of adaptive feedback systems, artificial intelligences or stored-programme computers which modify their own programmes, Fitts (1964) prescribed that a more accurate description of this problem may be achieved.

Fleishman and Hempel (1956) and Fitts (1951) emphasized the necessity to investigate the relative importance of exteroceptive and proprioceptive cues in the course of learning and Fitts (1951) suggested that '. . . visual control is important while an individual is learning a new perceptual-motor task. As performance becomes habitual, however, it is likely that proprioceptive feedback or "feel" becomes more important.' Experimentation revealed that proprioceptive cues are of the greatest relevance during later stages in learning (Fleishman and Rich, 1963). Fleishman and Rich (1963) considered that in the first few trials exteroceptive cues provide information for the guidance of movement indicated by the target course. Fitts and Posner (1967) suggested that three phases may be identified in the learning of repetitive or habitual tasks. In the first or cognitive stage the learner discovers the objectives of the task and identifies responses and stimuli which are relevant for its completion. For the second stage or associative phase, the relevant stimuli and responses are matched and although errors still occur, the learner is aware of the mistakes made and the reasons for them. During this phase the errors are gradually eliminated. In the final autonomous phase of skill learning, component processes become increasingly autonomous, less directly subject to cognitive control, and less subject to interference from other ongoing activities or environmental distractions.

Proprioceptive Sensitivity and Learning

Does the highly skilled individual respond to more relevant cues more accurately, or is he also more sensitive to any proprioceptive stimuli? Some evidence exists that this is the case. Phillips and Summers (1954) indicated that the proprioceptive sensitivity was greater in the dominant arm than in the non-dominant. This could indicate that the increased experience of movement and proprioceptive feedback from the dominant arm had caused a reduction in the thresholds to proprioceptive stimuli compared with the non-dominant. Lloyd and Caldwell (1965), in their investigation into active and passive sensitivity of the leg, indicated a learning influence. They found position sensitivity to be greatest within that arc of the leg used in normal gait.

The skilled performer may therefore be afforded a distinct advantage over the novice. He has identified and attends to the relevant rather than irrelevant stimuli, increased his efficiency of responding by identifying spatial or temporal patterns of stimuli and, since he has become familiar with the task, may also have increased sensitivity to proprioceptive stimuli.

Proprioception and Transfer of Training

The transfer of training in the laboratory is usually defined as 'the effect that the practice of one task has upon the learning or performance of a second.' (Cratty, 1967). Gibbs (1970) has credited proprioception with a salient role in this process. He argued for a hierarchy of control loops and proprioceptive control loops. As learning progresses, changes in the relative importance of a control loop may occur. This position is similar to that of Fitts (1951). The amount of transfer of skill or the type of transfer that will occur in a given situation is dependent upon the control loop in operation. Tasks which demand visual monitoring and are similar in respect of response characteristics show large amounts of positive transfer, since the same control loop is effective in both situations, despite other marked differences between the tasks.

Proprioception and Training: Information Feedback

Feedback is intrinsic to activity. Subjects may, however, receive information from the experimenter over which the subject has no control. Traditionally, though not exclusively, this information has been given verbally by the experimenter, but there is no reason why this external information cannot be given through any modality.

In the learning of any task an experimenter may provide various forms of information feedback, the categories of which have been listed by Holding (1965). He suggested that the information may be concurrent or terminal, i.e., information may be given at the end of the task or trial, or during its execution. If a subject is told that a previous response is correct, presumably he is able to identify the proprioceptive feedback with which that response was associated. Over a number of trials, therefore, the subject should learn what a correct response 'feels' like. Adams (1971), in his closed loop theory of motor learning regarded this response to information as an essential although transient phase.

Knowledge of results is of critical importance for the acquisition of skill; the more detailed the information, the more enhanced the learning. By blindfolding subjects so that accuracy of responding may not be observed, different qualities of information may be provided to the subject. Thorndike (1927), in a line drawing task, revealed that the greater the detail of information provided verbally to the blindfolded subject, the more accurately the subject identified the correct proprioceptive feedback and the better the performance. Other investigations support these findings of Thorndike (Cason, 1932; Seashore and Bavelas, 1941). Holding (1965) noted that highly precise information feedback may be descriptive of later performance. Holding and Macrae (1964) demonstrated that over-precise information feedback during training may act as a 'crutch' and after its removal performance may significantly deteriorate.

Bilodeau (1966) maintained that information feedback may have reinforcing and motivating properties as well as being directive. Delay of information feedback appears to have a different effect upon these properties. For example, reinforcing stimuli decrease in effectiveness as controllers of behaviour with increasing delay. The degree to which information feedback fulfills either of these roles may determine the degree to which delay influences the learning process.

Measures of Body Balance

One of the significant aspects of proprioceptive measurement using gross body movement has come in the form of measures of body balance of various kinds. Balancing is essentially an activity requiring intersensory co-operation, but those studies which have examined body balance in the absence of visual cues are perhaps most significant in this context. The fact that vision does play an important part in ability to balance has been effectively demonstrated by both Dickinson (1968) and Leonard (1966). Miles (1950) and Edwards (1946) have shown that in sighted adults body sway increases by as much as 50 percent to 100 percent when visual cues are removed. The phenomenon of deteriorating performance following the removal of visual cues has been demonstrated in both static and dynamic balance (Travis, 1945).

Several tests for balance ability have been designed. These tests may be divided into categories of static body balance and dynamic body balance. Bass (1939) suggested that static balance consists of equilibratory activity in which the body does not move while competent performance is continuing. Dynamic balance is defined as the maintenance of equilibrium whilst the body is undergoing changes of position. Travis (1945) and Graybill and Fregly (1965) found no significant relationship between static and dynamic balance as defined by Bass.

In 1944 Travis (1945) produced an apparatus for the measurement of dynamic balance which he named the stabilometer. This consisted of a platform on a universal joint on which the subject stands, attempting to maintain the platform in a close-to-horizontal position (see Figure 3). Similar instruments have been devised by Begbie (1966) and Reynolds (Slater-Hammel, 1956). These divergent techniques of measurement have produced generalizations regarding the development of balance ability. Hellebrandt, Braun and Tepper (1937) showed that body sway is endemic to upright stance. They suggested that the function of body sway is that it provides a constantly varying stimulus which could be responsible for the relative indefatigability of postural tone. In addition, constantly varying stimuli may also mitigate proprioceptive adaptation in the postural muscles.

Much of the developmental research has concerned itself with balance ability between 10 and 18 years of age. The reason for this may be found in the apparent clumsiness of teenagers which has been ascribed by some to deficiencies in balance. Seashore (1938) showed that balance ability increases with age. Despite contentions that rapid growth in preadolescence and adolescence may cause temporary reversal of balance ability, no researchers support a decrease of ability during adolescence, but many note a slowing of the rate of the development of balance ability (Espenschade et al., 1953; Cron and Pronko, 1957; Wallon et al., 1958).

Sex differences have been reported in both static and dynamic balancing. In dynamic balance, Travis (1944) found that females were better at a dynamic balance test than males and in a later study (Travis, 1945) that females recovered more quickly from rotation as measured by their ability to balance. Cron and Pronko(1957) supported this position in younger age groups but found that males were superior after puberty. On the other hand, Goetzinger (1961) and Bachman (1961) could find no difference in dynamic balance ability between the sexes.

In summary, the evidence from studies of balance indicates that this activity is the product of three distinct factors. Firstly, both vestibular and other proprioceptors participate in maintaining equilibrium. Secondly, vision enhances this performance and makes some types of dynamic balance possible, and finally, acquired skill enables the performance of balanced activities.

Balancing Ability Related to Performance

Since Fleishman (1964) has noted that balancing is an important factor in gross motor activity and since proprioceptive components are highly important in balancing, to consider balance as an underlying proprioceptive ability in gross motor performance is justifiable. A considerable number of studies have attempted to relate balance ability to the performance of physical skills. Of the more recent studies, Slater-Hammel (1956) showed that balance ability discriminated between athletes and non-athletes. Varsity athletes were found to be significantly better than physical education majors, and physical education majors were superior to liberal arts majors. Espenschade et al., (1953), in their studies with adolescent boys, noted that balance ability is correlated with performance in those skills necessary in the physical education programme. Mumby (1953) has shown that proprioceptive sensitivity and balance ability are related to wrestling skill. Fearing (1924) could find no relationship between ability to balance and athletic skill.

Proprioception and Vision in Performance

Gibbs (1970) introduced the concept of the relationship between visual and proprioceptive systems in performance. In the vast majority of tasks the visual direction of performance appears to be of paramount importance. All movements with an objective external to the organism must require and utilize information derived from the exteroceptors as well as the proprioceptors. Vision is the more dominant modality in mirror tracing tasks, as performance in such tasks is far inferior to performance using direct observation of the hand. The problem appears to be the conflicting sets of information derived from visual and proprioceptive sources. Obviously, the type of skill involved will determine to a large extent the relative importance attached to proprioceptive versus visual information. For example, in many sports skills, the positioning responses must be carried out without visual information, since vision is wholly occupied by tracking a target. In many over-learned skills, performance is most usually delegated to proprioceptive control, releasing vision for other purposes.

Pursuit-Rotor Tracking

The intricacy of the inter-relationships of the proprioceptive and visual sensory systems have proven exceedingly difficult to measure. The majority of instrumentation for studying proprioceptive-visual co-ordination was designed for pilot and astronaut testing and training, and is unsuitable for less-sophisticated motor performance research.

Koerth (1922) developed the pursuit-rotor machine, a target-tracing apparatus, for the purpose of conducting research on learning. Since its inception into psychological and education research, the pursuit-rotor task has been utilized in a wide range of investigative activities. The most popular area of research for this hand-eye co-ordination task was the question of massed versus distributed practice. The versatility of the apparatus, particularly its variable speed control, has predisposed its service to other research endeavours. Leonard et al., (1970) studied the effects of task difficulty on transfer performance on pursuit-rotor tracking. The difficulty level was easily incremented by increasing the rotary speed of the machine. Lordahl (1963) studied the effects of weight-contrast illusion on rotary-pursuit performance by using two weights of stylus and a weight-lifting task between trials. The two weights of stylus had no significant effect on time-on-target scores.

Theories of Tension and Performance

An obvious relationship exists between degrees of muscular tension and levels of motor performance involving simple and complex movements. However, the exact manner in which tension affects motor performance and learning has been a question eluding researchers for many years. Various theories concerning the relationship of muscular tension to general psychomotor processes have been advanced. Initially, a "peripheral" theory was suggested by Davis (1937), which held that any changes in tension patterns were intimately related to psychological processes. Myer and Noble (1958) advanced one of the most comprehensive explanations involving the rate of muscular tension and the manner in which it affects mental and motor performance. They proposed that impulses from tension converge on motor patterns and interact with the responses, and further suggested that the effect of tension on performance depends on the amount of tension, the proximity of the tension to the performing musculature, and the stage of practice during which the tension is induced.

An increasing amount of evidence has been found that points to the existence of what has been termed "general muscular tension". Goldstein (1964) suggested that individuals may be ranged on a continuum from those who are relaxed to those who habitually exhibit a degree of muscular tension in excess of that necessary to perform life's activities. The extensive review of the research in this area by Duffy (1962) also brought that authoress to the conclusion that although tension is manifested in specific ways, and has specific influences on various facets of behaviour, "there appears to be both some degree of 'generality' and some degree of 'specificity' in activation." (1962).

Measurement of Tension

From a review of the literature, Davis (1937) outlined several ways in which tension levels have been measured. These include the measurement of pressure changes in the grip of various performing instruments, or the force with which subjects strike the keys of a typewriter, or other types of experimental response keys. Wenger (1938) in an attempt to determine what constituted muscular tension compared individual subjective ratings of subjects, and then attempted to determine what kinds of physiological variables correlated with the observational ratings. Galvanic skin responses (GSR, currently termed Electrodermal Response or EDR), respiration, diastolic pressure, and dermographic latency combined to produce a score that seemed to be most predictive of muscular tension. Nidever (1960) combined some of the same measures to determine whether a general factor of muscle tension existed. He found that in 19 of the 23 muscle groups tested such a general factor did emerge. This researcher found that mental work implied concomitant physical work, insofar as increased tension was found to occur in the frontalis muscles during a serial verbal learning task. Eason (1963) found that the neck muscles seemed the best indices of general muscular tension, followed closely by the frontalis muscles.

More recently, the magnitude of electric impulses produced by the muscular action itself, as measured by the electromyograph, has been used to determine tension levels. A general assumption is that the level of electric output (computed in microvolts) is a direct measure of the tension present, and therefore serves as a particularly accurate method of assessing tension levels. De Vries (19) has derived a co-efficient of correlation of .9. The instantaneous feedback provided for the learner serves as a reinforcing response which may be employed in behaviour shaping or tension control experiments.

Effects of Tension on Motor Performance

Numerous investigations have been devoted to the study of the influence of induced tension on motor performance. In general, the findings parallel those of verbal-tension, mental-tension comparisons.

Some tasks usually the less complex, have been facilitated by tension, but others, the more complex, are usually inhibited.

In 1932, Russell (1932) used as a variable the experimenter's request to subjects "to tense", "to remain as normal", or "to consciously relax the body" when throwing a tennis ball for accuracy. He found that the normals threw best, the individuals who had been requested to relax were next, and the most inaccurate throwers were the tense subjects. The validity of Russell's findings might be questioned, however, even if his method of inducing tension is ignored, for Freeman (1937) suggested that individuals trained to tense or to relax their bodies showed benefits from such training in subsequent trials.

Although researchers have proposed that motor performance follows a U-shaped curve with respect to degrees of muscular tension induced (maximum performance, reaction time, and movement speed are elicited at the intermediate levels of tension), in a recent review Martens (1971) suggested that the available evidence did not suggest such a straightforward hypothesis between tension-arousal and motor performance. In a study by Marteniuk (1969), faster movement times were recorded when preliminary muscular tension was increased from zero to five through 10, 15, and 20 pounds. However reaction times followed the hypothesized U-shape trend. In 1969, Berger and Mathews (1969) found that a pre-relaxed condition permitted greater velocities to be imparted to a weight-lifting task than when the muscles were pre-tensed just prior to performing the task.

Effects of Tension on Motor Learning

Stroud (1931), one of the initial investigators to measure tension changes during the learning of a motor task, used the downward pressure his subjects exerted on a stylus in a maze problem as the tension score. He found that more tension occurred as the subject learned the more difficult portions of the maze. He also noted that tension decreased as learning progressed. Stroud also found that, when additional tension was added by requiring the subject to hold a pulley weight with the nonperforming hand, more tension also was evidenced in stylus pressure. Stroud explained his findings by reference to the concept of facilitation and hypothesized that the nerve impulses having different sensory origins summated to aid in the production of a response.

Daniel (1939), using action potential as a tension measure, produced results parallel to those of Stroud (1931); as learning progressed, tension decreased. Daniel also found that decreased tension was associated with error elimination, while increased tension produced greater speed.

Ghisseli (1936) discovered that as an individual learned a visual-motor task, tension tended to decrease. Eason (1963) found that improvement in performance was recorded on a tracking task while muscular tension, measured in the neck muscles, remained the same.

Theories Relating Tension to Performance and Learning

Several hypotheses have been advanced to explain tension-performance-learning relationships. Some investigators suggested that the constancy of kinesthetic stimuli as the result of tension raises the level of recruitment and facilitation in all muscle groups through cortical stimulation. Should this theory indeed have foundation, then relaxation or tension control of a particular muscle, e.g., the frontalis, mediated through the cortex, should bring about concomitant tension reduction through the body. Freeman (1938), on the other hand, first proposed that muscular tension levels, when increased, lower the threshold of excitability in the higher nervous centers, and, as a result, accurate complex performance may be inhibited. More recent investigations by Pinneo (1961) and Kempe (1956) indicated relationships between muscular tension and more basic neurological and physiological measures. Pinneo concluded that "proprioceptive return from induced muscular tension produces generalized behavioural and physiological effects in the reticular activating system" (1961). The relation of tension to total behaviour therefore appears to be a function of the amount of tension induced, the unique characteristics of the nervous system of the individual, and the locale in which such tension occurs.

Effects of Tension Control on Performance

Several writers have presented programs for producing relaxation and for elevating tension through various mystical or pseudo-scientific approaches to mind-body problems. A widely accepted method for promoting relaxation, which provides the basis for virtually all professional relaxation programmes, is Jacobson's theory of Progressive Relaxation (1938). Writing for physicians and scientists, Jacobson developed a technique for sequentially learning to control tension of muscles throughout the body to dispel "residual tension". The underlying principle of the Jacobson method is to heighten the individual's self-awareness of tension so that he or she can more completely and efficiently relax. Electromyographic biofeedback has the potential to heighten sensitivity to muscle tension to a degree far beyond that reached by Jacobson's subjects, and in a fraction of the time.

Benson (1958), indicated that application of the Jacobson method contributed positively to efficient total body movement. The ability to relax was assumed to play an important role in learning to swim, as was the fact that training in relaxation would speed the learning process of beginning and intermediate swimmers. The swimmers who were given relaxation training (not biofeedback type) progressed more rapidly than those who were not. Other more recent studies also have supported the effectiveness of aiding individuals to perceive better their residual muscular tensions on motor performance and skill learning. In 1971, Paben and Rosentsweigh (1971) found that performing and learning a novel paddle ball task were facilitated most in subjects who were "taught how to relax". No research appears in the literature in which electromyographic biofeedback techniques were implemented to control tension for the purpose of investigating motor performance and motor skill acquisition.

Electromyographic Biofeedback and Tension Control

Basmajian (1974), one of the pioneers of electromyographic biofeedback training, has proven that an individual can reduce muscle tension in some muscles to zero; that is, no motor unit activity is detectable, a condition that was previously thought impossible. Basmajian et al. (1963, 1965) have taught individuals in a matter of minutes to fire individual motor units within the muscle at cadences that imitate drum rolls and galloping horses, and to keep time to music. Basmajian (1974) is currently monitoring and recording complex muscle-tension patterns elicited by musicians and athletes, with the possible outcome that someday an amateur may be taught to develop the technique of the professional through biofeedback training. Green et al., (1969, 1970), following confirmation of Basmajian's studies of the single motor unit principles, rapidly extended biofeedback training into clinical investigations of the effects of feedback relaxation. They combined this with other forms of electronic feedback and applied the results to a variety of general and local tension states believed to be the cause of pathological physiology. At the same time, Gaarder (1971) was exploring practical means to control relaxation in patients with feedback devices.

Mathews and Gelder (1969) studied the effects of relaxation training with phobic patients and demonstrated that electromyographic activity was reduced during relaxation. They concluded that relaxation is associated with a controlled decrease in "arousal level" with retention of consciousness. Wilson and Wilson (1970), while agreeing that muscle tension could be manipulated by feedback and conditioning, were much less sure of the desirable effects of relaxation.

Whatmore (1968) used relaxation training by electromyographic biofeedback to treat patients with serious psychosomatic illnesses. Other therapists, such as Wolpe (1969), Schultz and Luthe (1959), and Malmo (1970) have come to the same conclusion as Whatmore with respect to the beneficial effects of deep muscle relaxation by electromyographic monitoring. The evidence from their investigations dictates that anxiety cannot exist in the presence of deep muscle relaxation.

From the generalized application of reducing stress and anxiety to specific problems involving residual muscle tension, electromyographic biofeedback has an incredibly wide range of applications. Budzynski, Stoyva, and Adler (1970) developed a technique to train subjects to overcome tension headaches. Electrodes were placed on the forehead and the reduction of tension in the frontalis muscles appeared to generalize over the entire upper part of the body. Budzynski and Stoyva (1971) later applied biofeedback techniques to speed up the process of systematic desensitization of phobias, a method developed by Wolpe (1969).

Electromyographic biofeedback has successfully been applied and current research is underway in such endeavours as rehabilitation of stroke and braindamaged patients, curing of insomniacs, and re-education of muscles in patients recovering from extensive immobilization and paralysis.

Neurophysiological Basis of Electromyography

The Motor Unit

The structural unit of muscular contraction is the muscle cell or muscle fibre. For normal mammalian skeletal muscle, muscle fibres probably never contract as individuals, but rather as small groups containing, on the average, from 10 to 1000 fibres. All of the fibres within each group are supplied by the terminal branches of one nerve fibre whose cell body lies in the anterior horn of the spinal grey matter. This nerve cell body and the long axon of this motor nerve, plus its terminal branches and all the muscle fibres supplied by these branches, together constitute a motor unit. The motor unit is the functional unit of striated muscle, since an impulse descending the nerve axon causes all the muscle fibres in one motor unit to contract almost simultaneously.

Motor units normally contract immediately upon the arrival of such nerve impulses as various frequencies, usually below 50 per second. This frequency seems to be the upper physiological limit for the frequency of propogation of axonal impulses, and such factors as a necessary recovery period and the threshold of fatigue in nerves must be involved in determining this frequency. The tension manifested by contraction of a specific muscle is the summation of asynchronous volleys of impulses being propogated along the various axons that innervate the motor units of the muscle. All the motor units are contracting and relaxing with twitch-like action at different rates up to 50 per second. The result of a continuous shower of twitches with different frequencies within a muscle is a smooth contraction.

Motor Unit Potential

When an impulse reaches the myoneural junction or motor endplate where the axonal branch terminates on a muscle fibre, a wave of contraction spreads over the fibre resulting in a brief twitch followed by rapid and complete relaxation. The duration of this twitch and relaxation varies from a few milliseconds to as long as 0.2 seconds, depending on whether fast or slow twitch fibres are innervated. During the twitch, a minute electrical potential, with a duration of only one to four milliseconds, is generated and is dissipated into the surrounding tissues. Since all the muscle fibres of a motor unit do not contract at exactly the same time--some being delayed for several milliseconds--the electrical potential developed by the single twitch of all the fibres in the motor unit is prolonged to about five to 12 milliseconds. The electrical result of the motor unit twitch is, therefore, an electrical discharge with a mean duration of about nine milliseconds and a total amplitude or action potential measured in microvolts. The amplitude of the action potentials in various muscles depends upon the total number of motor units in the muscle. Generally, therefore, the larger the muscle the larger the amplitude of the action potentials.

Motor Unit Recruitment

Recent research in electrophysiology has demonstrated that under normal contractile conditions, the smaller action potentials appear first with a slight contraction. As the tension is increased, larger and larger potentials are recruited, and all motor units increase their frequency of firing (Henneman et al., 1965; Olsen et al., 1968; Ashworth et al., 1967; Grimby and Hannerz, 1968, 1970). This is considered the normal pattern of recruitment.

Measurement in Electromyography

Basically, an electromyograph is a high gain amplifier with a preference or selectivity for frequencies in the range from about 10 to several thousand Hz (cycles per second). Hayes (1960) suggested that the sharply peaked spectra of motor unit potentials derived with surface electrodes make the use of amplifiers with limited frequency response practical. He found several advantages in rejecting frequencies below 20 Hz and above 200 Hz. "Amplifier noise, general nonmuscular 'tissue noise' and movement artifact were largely eliminated without significant loss of motor unit potentials" (Hayes, 1960). When a single stimulus arrives at the neuromuscular junction, two electrical responses are externally measurable via the electrodes of the electromyograph. Firstly, the fibre membrane fires, giving an electrical impulse to be picked up by the electrodes. Secondly, a twitch occurs, rising to a maximum twitch force and falling off again, and of much longer duration than the impulse. If two stimuli arrive close enough together, the two twitches will fuse, giving a higher maximum; and with three, somewhat higher yet, and so on. If stimuli continue to arrive sufficiently quickly, this fusion of twitches becomes virtually complete, giving a quite steady maximum force typically four times that of a single twitch maximum. Although these muscle twitches overlap and fuse, the electrical impulses from the fibre firing never overlap.

According to Adrian and Bronk (1928, 1929), "During voluntary contraction the discharge of single motoneurons varied between five and 50 impulses per second as the contraction increased from light to maximal effort." Ruch et al., (1963) explained:

> "As more force is required, three things happen in an overlapping sequence: (i) more motor units are activated (recruitment), (ii) the active motor units discharge more frequently but not rapidly enough for muscular summation (i.e., the response is subtetanic); and (iii) with further increase in frequency, the motor unit twitches summate to form a tetanus."

Therefore, the electrodes receive signals of overlapping stages of mechanical twitches and, as a unit is recruited, the action potential of the firing fibre membrane provides an impulse four times the maximum of the twitch impulse when a steady contraction is held.

When motor units fire randomly, some fire simultaneously, which increases the signal at that point. Recruitment of large numbers of motor units, with the increased chance of simultaneous firing, produces more muscle tension. Lippold (1952) has found correlations of 0.93 to 0.99 between muscle tension and integrated EMG recordings from surface electrodes. Such correlations have been corroborated by many investigators.

Surface electrode electromyography, in most kinesiological and medical applications, typically measures action potentials of the amplitude of 100 to 3,000 microvolts. When relaxation states need to be evaluated, the action potentials in relaxed muscle are in the range of 0 - 100 microvolts. Deep relaxation may produce "electrical silence", as the studies by Basmajian (1963, 1965) have shown. Disagreement exists about the source of electrical activity in the very low range of 0 - 10 microvolts, recorded from deeply relaxed muscles. However, with technologically superior instrumentation which frequently is designed to measure at very low levels of electrically activity (such as the electromyograph used in this investigation), the problem of accurate sensitive recordings is avoided.

Integration of Electromyographic Potentials

Investigators in electromyography became dissatisfied with visual analysis of primary records and turned to integration of potentials as a solution. Integrators are electronic devices which produce, when electromyographic signals are transmitted to them, an arbitrary quantitative figure derived from the variables of amplitude, frequency, and spike shape. Comparisons of electromyographic activity are made simple on a quantitative basis, and qualitative data are feasible with sophisticated integrators which permit threshold filtering, averaging of amplitude and waveform analysis.

Electromyography of the Frontalis Muscles

Budzynski, Stoyva and Adler (1970) developed a technique to train subjects to overcome tension headaches. Electrodes were placed on the forehead and the reduction of tension in the frontalis muscles appeared to generalize over the entire upper part of the body. Intrigued by the fact that many psychologists were using the frontalis muscles as a reference area for muscular tension studies, Vitti and Basmajian (1973) studied the frontalis area with surface and fine wire electrodes. They found low amplitude activity in the muscle, and reported no significant change in its activity with postural variation. Sumitsuji et al. (1967) reported that frontalis activity did however decrease when their subjects assumed a supine relaxed position. Vitti and Basmajian (1973) explained that the frontalis became active on demand or in response to specific (perhaps uncontrolled) emotional states or expressions. The inference drawn from these investigations by this writer was that the frontalis muscles appeared extremely suitable to monitor for tension-anxiety manifestations in this current research investigation.

Summary

The physiological and psychological principles of motor skill learning and performance, and their intricate inter-relationships with respect to biofeedback training for tension control have been reviewed in this chapter.

Within the past decade, man has become less accepting of the several black box theories of fine motor control and more accepting of advances in psychobiological research that has delved into the mysterious depths of unconscious and subconscious control. Biofeedback research, despite its novelty and fad-like impact on modern society, was established on scientific bases, and derives its support from scientists, physicians and psychologists through the world. Natural biological feedback systems have long been recognized as the basis of proprioception for movement control. Modern technology has produced instruments capable of tapping these biological systems and augmenting feedback so that conscious registration of feedback messages occurs.

Biofeedback researchers have demonstrated the effectiveness of electromyographic biofeedback in the facilitation and inhibition of factors producing muscle tension (Basmajian et al., 1963, 1965; Basmajian, 1974; Green et al., 1969, 1970; Gaarder, 1971; Mathews and Gelder, 1969; Wilson and Wilson, 1970; Whatmore, 1968; Wolpe, 1969; Schultz and Luthe, 1959; Malmo, 1970; Budzynski, Stoyva and Adler, 1970; Budzynskiand Stoyva, 1971).

Numerous investigations have been devoted to the study of the influence of tension on motor performance and learning (Russell, 1932; Freeman, 1937; Martens, 1971; Marteniuk, 1969; Berger and Mathus, 1969; Stroud, 1931; Daniel, 1939; Ghisseli, 1936; Eason, 1963). These authors substantiated high positive correlations between motor performance and low muscular tension with similar correlations between motor learning and low muscular tension. The presence of residual muscular tension was shown to be detrimental to the performance and learning of motor activities.

The need for an investigation of the effects of electromyographic biofeedback for tension control during motor skill acquisition became apparent in view of the precedent research.

CHAPTER III

METHODS AND PROCEDURES

All research and preparation of this dissertation was completed at Oregon State University, Corvallis, Oregon during the 1975-76 academic year. Previous research demonstrated high positive correlations between motor performance and low muscle tension with similar correlations between motor learning and low muscle tension. The presence of residual muscle tension has been shown to be detrimental to the performance and learning of motor activities.

The advent of biofeedback technology in the 1970's provided a means to train individuals to reduce residual muscular tension. The intent of this investigation was to test whether such training may improve performance of fine and gross motor skills, since residual muscular tension appears to be a common deterent in most novel motor tasks.

Subjects

Approval of the use of human subjects for this investigation was granted by the Oregon State University Committee for the Protection of Human Subjects (Appendix A).

Thirty male college student volunteers served as subjects for this investigation. The subjects, all members of a university living group for which this investigator served as the resident adviser, were selected on the basis of availability and willingness to participate in the study. Initial contact with the living group was made at a meeting during which all members of the group were informed of the research project. A letter was distributed to each member two days later describing the nature of the study, the test procedures and time required, and requesting signature of a statement demonstrating willingness to participate (see Appendix B). When all agreement forms had been returned, a master testing schedule was posted and all volunteers were asked to register for individual test sessions within prescribed hours. The pre-test and post-test sessions were scheduled at the same time of day and day of the week four weeks apart. The pre-test and post-test sessions were conducted in the Psychophysiology Laboratory in the Psychology Department at Oregon State University.

The pre-test session consisted of a subject orientation and the entire pre-test. Upon arrival for his appointment, each subject was asked to view and listen to a synchronized slide-tape presentation which outlined the procedures of the test and illustrated techniques for the two skills to be performed. This method of instruction was employed to 1) standardize the information presented to each subject to avoid differentiation of learning cues given by the investigator and 2) facilitate the orientation of the subject. Each subject was invited to ask questions when the slide-tape presentation concluded, and replies were given to clarify the methods and procedures of the skills tests.

Each subject was asked to complete a demographic survey form before testing commenced (see Appendix C). Specific information requested involved the subject's evaluation of his academic stress at the time, a subjective evaluation of his tension state, and a statement on his work-load stress, and his use of medication and drugs, all of which may affect performance and learning. Approval of the use of this form had been granted by the Oregon State University Committee for the Protection of Human Subjects on the condition that each subject was informed of his right to refuse comment on any requested information, and that the information would be kept strictly confidential. This condition was steadfastly adhered to.

The demographic data was not used for classification purposes and was not analysed for differences or trends, since the test data collected, in the final analysis, did not indicate a need for such procedure. Had any subjects demonstrated unusual performance data during pre-testing or post-testing, this demographic data may have proven valuable in analysing deviant trends.

The assignment of subjects to treatment groups was dependent upon the results of the pre-test sessions of all subjects. This feature of the investigation will be described in the discussion of experimental design.

Equipment

The Electromyograph and Integrator

One criterion instrument used in this investigation to evaluate muscular tension was the Feedback Electromyograph, Model BFT 401C produced by Bio-Feedback Technology, Incorporated. The Digital Time Period Integrator, Model BFT 215C was used to produce quantitative, integrated electromyographic data as a criterion measure for this research. These instruments were further employed in the tension control training of the subjects which was conducted between the pre-testing and post-testing sessions. Although integrated EMG (electromyograph) scores cannot directly be identified as tension scores, they can be considered very highly correlated to muscular tension (0.94 - 0.99) as particularly established by Lippold (1957).

The electromyograph was connected by three surface electrodes to the frontalis muscle area of the forehead. The active electrodes were placed on either side of the forehead about two centimetres above the eyebrows directly above the centres of the eyes. The reference electrode was located immediately between the active electrodes directly over the bridge of the nose. All three electrodes were attached to the skin by self-adhesive discs designed for that purpose. This method ensured a good connection throughout the testing and training sessions, and was preferable to a head-band connection, since it provided added comfort and far less pressure on the muscle area.

The Stabilometer and Pursuit-Rotor

A stabilometer balancing task was selected as a criterion gross-motor skill test, and was used to measure dynamic balance in this investigation. This apparatus was described by Bachman (1961) as follows:

> "This apparatus consists of a balance platform which pivots on a pipe axle. When either end of the platform touches the supporting base of the stabilometer (a deviation of approximately 30 degrees from the horizontal), a micro-switch is depressed."

The microswitches were connected in series with a 30 second timer which measured the total time (to the nearest 1/100th second) that the platform was in a "balanced position" during each 30 second trial (i.e., the amount of time during which the microswitches were not depressed). Modifications made to the standard stabilometer ensured a similar resistance to tilt for all tests and for all body weights of the subjects.

The Pursuit-Rotor tracking task was selected as a criterion fine motor skill test in this investigation. An advanced model of the pursuit-rotor, the Photoelectric Pursuit-Rotor produced by Lafayette Instrument Company, was used to measure pursuit-rotor tracking performance. The pursuit-rotor apparatus was originally designed by Koerthe (1922) to conduct research on learning. His machine has been modified extensively over the years as it has become a popular tool of educators and psychologists. The photoelectric model obtained for this research investigation consisted of a revolving flourescent light beneath an opaque glass cover marked with a transparent octagonal tracking path. The stylus, which was wired in series with a thirty-second timer, was connected to a photoelectric cell sensitive to the light emitted through the track. When the stylus was traced directly over the light source, the clock continued to run, but stopped when the stylus moved off-target. The variable-speed pursuit-rotor was set at 60 revolutions per minute for this investigation, a speed which was found, during a pilot study, to provide sufficient difficulty so as to induce a general tension level similar to that of fine-motor, manipulative skills.

Auxiliary Equipment

A shielded room was the site for all testing for this investigation. Sixty cycle and radio frequency interference rendered the electromyograph useless in all but this setting. An isolation transformer was also available which reduced electromagnetic effects in power lines and electrode leads. All AC powered equipment that couldn't be reduced to lower-voltage DC supply was electrically isolated to prevent noise interference.

The shielded room consisted of an eight feet by five feet by eight feet high wooden frame covered with copper screening sufficiently fine in mesh to exclude sixty-cycle wave amplitude. The screening was continuous to completely isolate the area within the cage.

Other equipment included a stop-watch to time intertrial intervals, a chair for the subject to sit upon between trials to reduce fatigue influence, and data forms (see Appendix D).

The only additional equipment required for tension control training was a comfortably padded, high-backed chair with arm rests, in which the subjects reclined to reduce muscular tension.

The BFT 401C feedback electromyograph, the BFT 215C digital time period integrator and the photoelectric pursuit-rotor are illustrated in Figure 2. The stabilometer appears in Figure 3.

Experimental Design

Thirty subjects were assigned to one of two experimental groups or a control group on the basis of their pre-test performance scores. The assignment of subjects to groups was based upon T scores computed from the mean time-on-target scores for the stabilometer balance and pursuit-rotor tracking pre-tests. The T scores provided

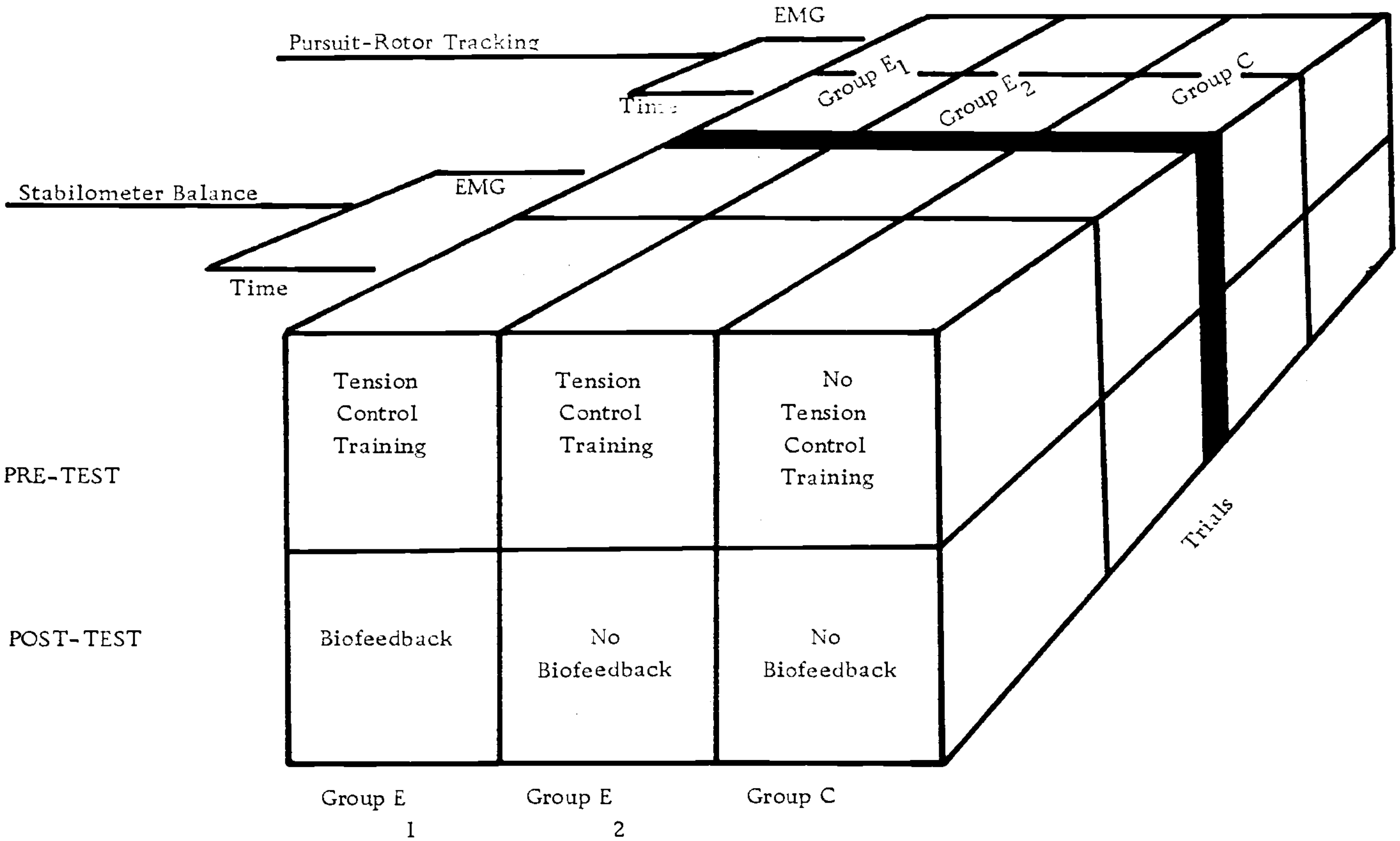

Figure 1. Factor Model of Test Design.

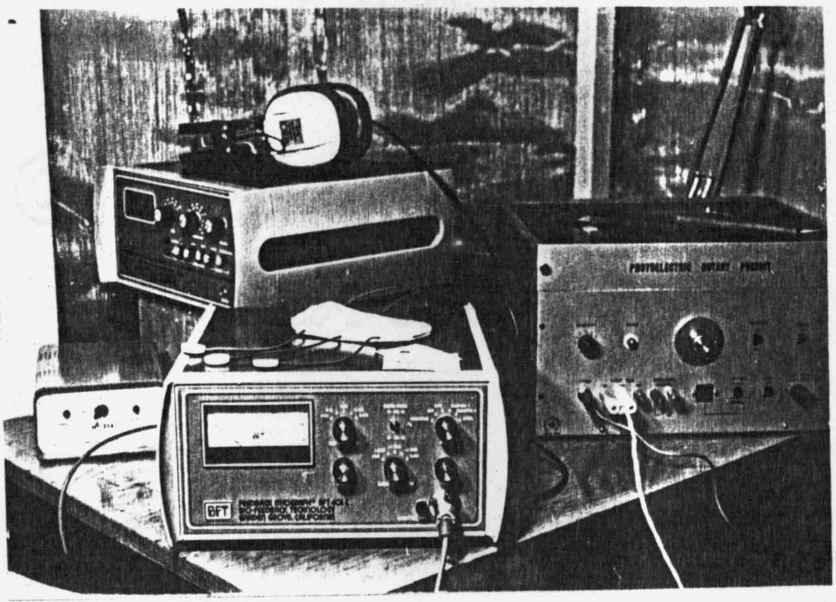

Figure 2. Test Equipment

Figure 3. The Stabilometer Balancing Task

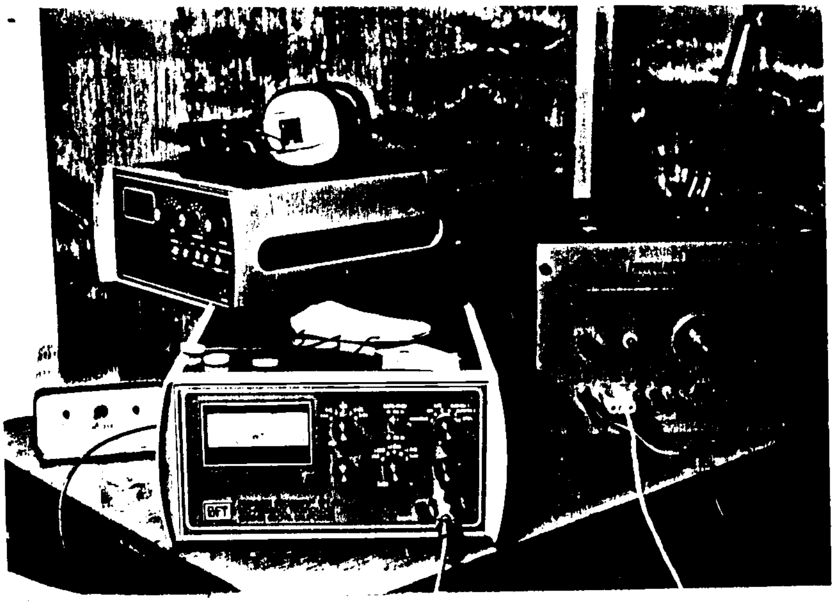

Figure 2. Test Equipment

Table I. Analysis of Pre-Test Data.

	Stabilometer Balance						Pursuit-Rotor Tracking					
	Time-on-Target (secs.)			Integrated EMG (μV)			Time-on-Target (secs.)			Integrated EMG (μV)		
	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C
Group mean	21.271	21.623	21.219	128.753	130.321	128.248	11.014	10.590	11.192	269.754	256.499	255.968
	LSD (.05) = 2.151			LSD (.05) = 23.745			LSD (.05) = 1.618			LSD (.05) = 66.578		
	F_c = .0879			F_c = .0177			F_c = .3118			F_c = .1173		
	F(2,24) = 3.40			F(2,24) = 3.40			F(2,24) = 3.40			F(2,24) = 3.40		
	No significant difference			No significant difference			No significant difference			No significant difference		

training identical to that of the first experimental group. The distinction of post-test treatments is provided again in Figure 1.

An analysis of variance groups by trials design and *t* tests served to test the hypotheses of this investigation. The structure and data analysis described and illustrated by Edwards (1960) were followed for statistical treatment. The experimental model is illustrated by Figure 1. Two experimental groups and one control group were treated by two tasks by pre-tests and post-tests. Two criterion measures, time-on-target of a 30 second test-period for both stabilometer balance and pursuit-rotor tracking, and integrated EMG scores in microvolts for the 30 second test-period, were used to test the null hypotheses.

The analysis of variance groups by trials statistical treatment of the data produced *F* values which were used to test hypotheses one, two, three, four, seven and eight. An analysis of pre-test to post-test scores produced *t* values which were used to test hypotheses five and six. A summary of the tested hypotheses and their statistical treatments and significance appears in Table V).

Co-efficients of correlation were also calculated to study the relationships of time-on-target performance scores and integrated EMG scores for pre-tests, post-tests, and post-test minus pre-test differences (Table II).

Test Description and Procedure

The pre-test and post-test procedures were identical except for the fact that one experimental group (E_1), was provided auditory bio-feedback during the post-test. Before testing commenced for the pre-test, each subject was informed of the test description and procedures by a synchronized slide-tape presentation which lasted approximately five minutes. A five-minute rest period was provided before the commencement of the post-test to permit the subjects the same opportunity to relax after arrival for their appointments. After the rest period, the electromyograph electrodes were attached and the equipment checked for proper function. The subjects were given headphones to reduce the possibility of distraction due to extraneous noise. A signal tone marking the end of each trial was provided via the headphones which communicated a signal from the EMG integrator. The first of the two tasks performed was the stabilometer balance, followed by a two-minute rest, and then the pursuit-rotor tracking task.

The Stabilometer Balance Task

This task was performed serially ten times, each trial lasting 30 seconds, with a one-minute rest interval between trials. The subjects were permitted one 30 second practice trial before testing commenced. A ready signal was given to the subjects approximately 15 seconds before each trial was to commence. On this signal, the subjects stood and took their positions on the stabilometer platform, checked their balance position for a few seconds, and then signalled the investigator when they were ready to begin. By a remote starter, the investigator activated the timing circuit which was synchronized with the timer on the EMG integrator. When the integrator timer signal indicated the end of each 30 second trial, the subjects stepped down and rested on the chair. Knowledge of results was not provided to the subjects at any time during pre-testing and post-testing, since all extrinsic stimuli were to be avoided. Following the tenth trial on the stabilometer, the subjects rested for approximately three minutes. The only communication between the subjects and the investigator during testing was to exchange questions and remind subjects of information on procedures and techniques that had been given previously during the orientation. Figure 3 demonstrates the performance of the stabilometer balance task.

The Pursuit-Rotor Tracking Task

The tracking task followed the completion of the stabilometer balance task. This task was performed serially ten times, each trial lasting 30 seconds, with a 30 second rest interval between trials. The subjects were given a 30 second practice trial before testing commenced. For each trial, the subjects were instructed to commence tracking, and after two revolutions, when the subjects were on target and tracking in rhythm with the 60 cycles per minute speed of the pursuit-rotor machine, the test commenced. The same timing circuits were utilized as were described above for the balancing test. During intertrial rest intervals, the subjects were instructed to relax their tracking arm and turn their eyes from watching the rotary light beam. Again, knowledge of results was withheld from the subjects. Following the tenth trial, the electrodes were removed and the subjects left the testing area. The investigator encouraged the subjects to refrain from discussing the experiment amongst themselves after the pre-test. Figure 4 demonstrates the performance of the pursuit-rotor tracking task.

Factors of Test Control

During all testing, external variables such as the presence of other persons and extraneous noises were avoided whenever possible. Ambient temperatures were kept constant and subject comfort was provided for in all possible ways. The subjects were encouraged to wear comfortable, loose-fitting clothing and sports shoes for the balancing task. They were also discouraged from eating heavily or performing intense exercise immediately before testing. Ample time was scheduled for each session to allow the subjects to relax before the test, and have sufficient time remaining after the test to reduce

Figure 4. The Pursuit-Rotor Tracking Task

anxiety about personal appointments and classes they may have had scheduled immediately after testing. The subjects were extended every opportunity to arrange a testing session time that suited them, so that tension induced by external factors was minimized. Several subjects were accommodated in this way when conflicting or interfering situations arose.

Tension Control Training

As described previously in Experimental Design, the thirty subjects were assigned to one of three groups on the basis of their pretest performance scores. Two of the three groups; that is, 20 of the 30 subjects, were assigned to tension control training scheduled for the three week interval between pre-testing and post-testing.

The site for tension control training was chosen for its convenience and suitability. A small, tastefully-furnished dimly-lit room at the residence of the subjects was particularly conducive to the training needs of the subjects. The familiarity of the setting, the convenience of location, and the quietness necessary for induced relaxation were advantageous prerequisites for optimal training effectiveness. A large, comfortable, high-backed chair with arm rests and the electromyograph and integrator were placed in the training room. Electrical interference was minimal in the locale, despite the absence of electrical shielding.

The subjects were requested to register for a 30 minute session at the same hour of day on a Monday-Wednesday-Friday sequence or a Tuesday-Thursday-Sunday sequence. This schedule, repeated for three consecutive weeks, provided the subjects with nine 30 minute training sessions. Of the 30 minutes scheduled per session, at least five minutes was utilized in preparing the subjects with electrode attachments and removal of electrodes after training. A minimum training time of 20 minutes was maintained. Low integrated EMG readings were logged by the investigator during training.

The Nature of Tension-Control Training

The following sequence of tension control training protocol was derived from methods developed by Jacobson (1938) known as progressive relaxation, from autogenic training methods popularized by Luthe (1963), and from modern electromyographic biofeedback techniques developed especially by Green et al., (1969, 1970) and Budzynski et al. (1970). Methods were adapted to produce a generalized ability to control tension, since the intent of this investigator was to develop and test a training program which could be used to reduce tension for all types of motor learning and motor performance situations. Therefore, any form of training that would specifically prepare the subjects for balancing or tracking tasks was strictly avoided. The following summary was intended to indicate the nature of the tension control training used in this investigation, and not to be an all-inclusive description. Figure 5 illustrates tension control training in progress.

Session 1: The subjects were instructed on the operation of the machine, since they were to adjust feedback controls to suit their needs during training. Various auditory feedback modes, which indicated EMG activity in specifically different ways, were provided to the subjects so that they might chose the mode personally most conducive to relaxation training. As the sensitivity of the feedback was dependent upon selective meter ranges (gain levels), the subjects were trained to adjust their own settings to maintain useable feedback. EMG readings in microvolts were displayed on the myograph galvanometer, providing a visual source of reinforcement during learning. The subjects were instructed how to use the feedback to reduce tension. Postural positioning was discussed so that excess tensions would be prevented. A third source of feedback which proved extremely valuable in training was the digital time period integrator. This instrument, triggered by a remote switch attached at the hand position of the chair arm-rest for convenience, provided a quantitative score for comparisons throughout training. Lowering of integrator scores motivated subjects during training. Rheostat-variable threshold adjustments permitted subjects to set the level of difficulty within reach, so that success would be guaranteed at some point during the session. At the conclusion of the first session, the subjects were familiar with the

Figure 5. Biofeedback Tension Control Training

operation of the machine, and had already, in many cases, learned to use the visual, auditory and digital display feedback to lower their EMG activity significantly.

Session 2: Emphasis was placed upon progressive sensitization of the body. The subjects were encouraged to sequentially concentrate on the tension levels they could feel by starting from the extremities (fingers or toes) and over a period of two minutes, gradually move away from this focus until all parts of the body had been considered. Auditory feedback training was stressed since most subjects progressed more rapidly with closed eyes.

Session 3: The subjects were extensively interviewed about their subjective feelings with respect to their training progress. The investigator reinforced postural and progressive relaxation cues depending on the problems encountered. Subjects demonstrating anxiety were encouraged to correct situations causing this tension manifestation, and were reinforced by the investigator when progress was made.

Session 4: The subjects trained by themselves, summoning the investigator only when difficulties arose. At this stage, most subjects worked very independently and were progressing very rapidly.

Session 5: Training continued as in session 4.

Session 6: For the last five minutes of this session, the subjects were requested to stand for training. The subjects utilized this time adjusting to the postural changes.

Session 7: The first five minutes were spent in normal tension control training. When five minutes had elapsed, the subjects held a ball-bearing maze instrument in one or both hands and attempted to move the ball-bearing from one end of the maze to the other. Subject variability was large with respect to success in the high difficulty manipulative skill. Following five minutes with the maze task, normal training was resumed for five minutes, or until EMG readings had returned to normal. The subjects were then instructed to shuffle a deck of cards over a card table arranged over their laps, and then deal the cards alternately to form two separate stacks at the rate of about one card per second, avoiding excessive movements. The final task was to divide the deck into three stacks, one for odd-numbered cards, one of even-numbered cards, and one of picture cards. Integrated EMG readings were recorded for each of these manipulative tasks, while subjects attempted to minimize tension throughout the session.

Session 8: Following five minutes of normal training, the trainees were subjected to various gross motor activities involving simple movements. Care was taken to avoid any practice of balance-like activities and tracking movement. Examples of required movements were 1) slow arm raises laterally while standing 2) slow squatting and standing 3) arm circling and 4) squat balancing. EMG readings were taken for each activity, and the activity was repeated to evaluate whether control was being achieved.

Session 9: For this final session, the subjects were permitted to concentrate on personal areas of weakness in tension control. No deviation from previous protocol was permitted.

One half of those subjects trained in the tension control techniques outlined above were provided auditory biofeedback during post-testing. The question raised by this experimental condition was whether or not persons trained by biofeedback augmentation could utilize the presence of the electromyographic biofeedback during the performance and learning of a relatively difficult novel motor task. The results of this investigation are discussed in Chapter IV.

Reduction and Analysis of Data

Raw scores were recorded on each subject's data form for all ten trials of each of the two tasks for the pre-test and post-test. The raw scores consisted of concurrent measurements of time-on-target and EMG integration in microvolts for each trial. Time-on-target scores were recorded with electronic timers accurate to 1/100th of a second connected in series. The electromyograph was returned to the manufacturers for calibration immediately prior to the pre-test sessions and was used exclusively for this investigation.

Analysis of variance groups by trials, analysis of variance of difference means and t tests served to test the hypotheses of this investigation. F or t values were used to determine the acceptance or rejection of each of the eight hypotheses with respect to the two criterion measures. Although time-on-target scores (performance scores) were the prime criterion measure for the testing of the hypotheses, similar analyses of the hypotheses were conducted using integrated EMG scores which represented the general tension levels of the subjects during performance. Therefore, each hypothesis considered separately the effects of the treatments upon performances and tension levels of the subjects. Correlation co-efficients were computed to analyse the relationships between time-on-target and integrated EMG scores throughout the investigation. Specific file codes for the programs used in the analysis of the data were OSU * ANOVA 12 and OSU * MCF. Criterion measures were transferred to computer cards, assigned and arranged in factor groupings and submitted for computer analysis. The data file was stored for accessibility by teletype and further analysis.

A level of significance of .05 was selected for rejection of the null hypotheses of this investigation.

CHAPTER IV

ANALYSIS AND INTERPRETATION OF DATA

The major purpose of this investigation was to study the effects of electromyographic biofeedback for tension control during skill acquisition. A stabilometer balancing test was selected to represent gross motor skill activity, and a pursuit-rotor tracking task was selected to represent fine motor skill activity. Thirty volunteer subjects provided data for specific tests of the above mentioned motor performance tasks before and after tension control training was undertaken by 20 of the subjects. Treatments and analysis of the data were established on the basis of an analysis of variance groups by trials design. A factor model of this test design appears in Figure 1. Descriptive statistics of the pre-test and post-test data for both criterion measures appear in Table II. The main effects tested include between group difference for pre-test and post-test data, pre-test to post-test differences for all groups, and interaction effects of groups by trials. A summary of the analysis of variance groups by trials tables appears in Table III. Criterion measures used in analysis of the data were concurrently-scored time-on-target performances in seconds and integrated EMG scores in microvolts. Correlation coefficients were computed to analyse the relationships of performance and tension during skill acquisition. The main effects are discussed

Table II. Analysis of the Data: Descriptive Statistics

		STABILOMETER BALANCING TASK					
		Time-on-Target			Integrated EMG(μV)		
Group	Trials	Mean	S.D.	t(16df)	Mean	S.D.	t(16df)
*E_1	Pre-test	21.27	2.22	-2.61[a]	128.75	22.83	6.04[b]
	Post-test	23.12	2.72		78.23	10.37	
E_2	Pre-test	21.62	2.47	-2.36[a]	130.32	16.31	7.08[b]
	Post-test	23.04	2.33		77.10	15.55	
C	Pre-test	21.22	1.90	-0.69	128.25	21.61	1.23
	Post-test	21.85	1.95		112.53	18.91	
Summed groups				-1.43			2.74[a]
		PURSUIT-ROTOR TRACKING TASK					
E_1	Pre-test	11.02	2.06	-2.68[a]	269.75	60.30	5.15[b]
	Post-test	12.46	1.54		155.25	28.62	
E_2	Pre-test	10.59	1.61	-2.55[a]	256.50	66.48	3.27[b]
	Post-test	12.52	1.60		165.65	50.44	
C	Pre-test	11.19	1.20	-0.41	255.97	57.40	0.83
	Post-test	11.46	1.51		231.10	46.27	
Summed Groups				-1.09			2.42[a]

a Significant .05 b Significant .01

* Key E_1 Experimental group trained in tension control which received auditory feedback during the post-test. E_2 Experimental group trained in tension control which did not receive auditory feedback during the post-test. C Control group which performed the pre-test and post-test only.

Table III. Analysis of Variance Groups x Trials Table.

Source	Ndf.	STABILOMETER BALANCE: Time-on-Target M.S.	Time-on-Target F	STABILOMETER BALANCE: Integrated EMG M.S.	Integrated EMG F	PURSUIT-ROTOR TRACKING: Time-on-Target M.S.	Time-on-Target F	PURSUIT-ROTOR TRACKING: Integrated EMG M.S.	Integrated EMG F
Groups	2	3.38	0.65	1691.2	3.88[a]	.76	0.29	6056.15	1.86
Trials	1	23.23	4.45[a]	21404.44	49.08[b]	19.86	7.68[b]	79504.94	24.40[b]
Groups x Trials	2	1.83	0.35	1968.87	4.51[a]	3.30	1.28	9711.43	3.22[a]
Error	48	5.22		436.07		2.59		3258.77	
Total	53								

[a] Significant at the .05

[b] Significant at the .01

below in the testing of the hypotheses. Meaningful interaction effects are presented when most appropriate in the analysis. Discussion of the effects follows data analysis.

Analysis of Data

Individual trial scores of time-on-target performance and concurrent integrated EMG activity representing tension were treated in an analysis of variance by groups for the stabilometer balancing task. A similar analysis for pre-test scores had previously revealed no significant difference between group means (Table I). An analysis of post-test scores also showed that no significant difference existed between group means of time-on-target scores, but a significant difference at the .01 level, was found to exist between the integrated EMG group means (Table IV). Figure 6 illustrates the pre-test to post-test trends of the three groups for the stabilometer balancing time-on-target scores. Figure 7 represents the integrated EMG group means for the pre-test and post-test for the stabilometer balance.

Individual trial scores of time-on-target performance and concurrent integrated EMG activity were treated in an analysis of variance between groups for the pursuit-rotor tracking task. A similar analysis for pre-test scores had previously revealed no significant difference between group means (Table I). The post-test analysis determined that no significant difference existed between group means

Table IV. Analysis of Post-Test Scores.

	STABILOMETER						PURSUIT ROTOR					
	Time-on-Target			Integrated EMG			Time-on-Target			Integrated EMG		
	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C
Group Means	23.12	23.04	21.85	78.23	77.10	112.53	12.46	12.52	11.46	155.25	165.65	231.10
					E_2 vs C: 35.43[b]						E_2 vs C: 65.45[b]	
	No significant difference			E_1 vs C: 34.30[b]			No significant difference			E_1 vs C: 75.85[b]		
	L.S.D. (.05) = 2.29			L.S.D. (.01) = 21.93			L.S.D. (.05) = 1.51			L.S.D. (.01) = 56.48		
	F_c = .86			F_c = 13.20			F_c = 1.33			= 8.29		
	$F_{.05(2,24)}$ = 3.40			$F_{.01(2,24)}$ = 5.61			$F_{.05(2,24)}$ = 3.40			= 5.61		

[b] Significant at .01 level.

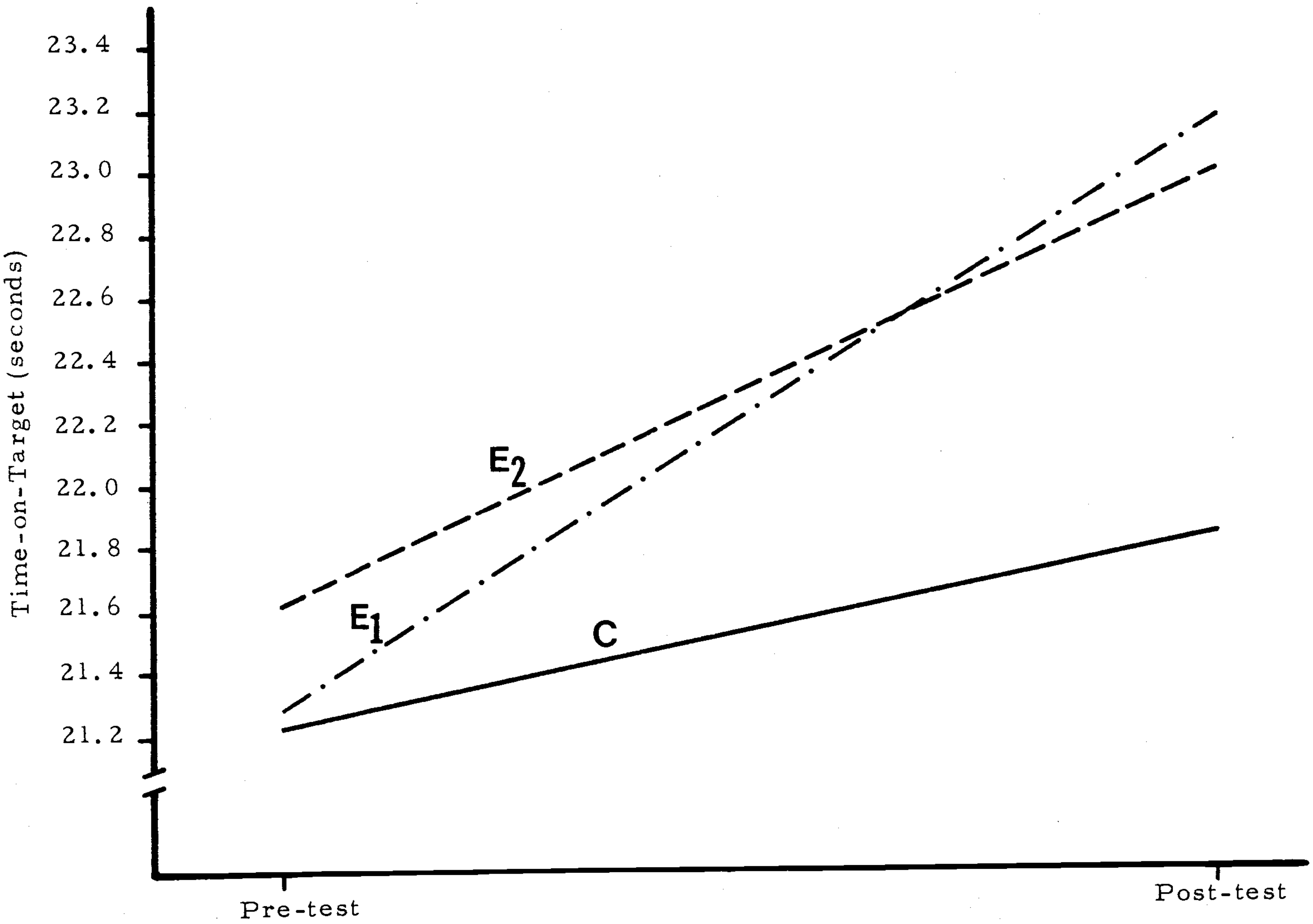

Figure 6. Pre-test to Post-test Group Trends for Time-on-Target Scores in Stabilometer Balancing.

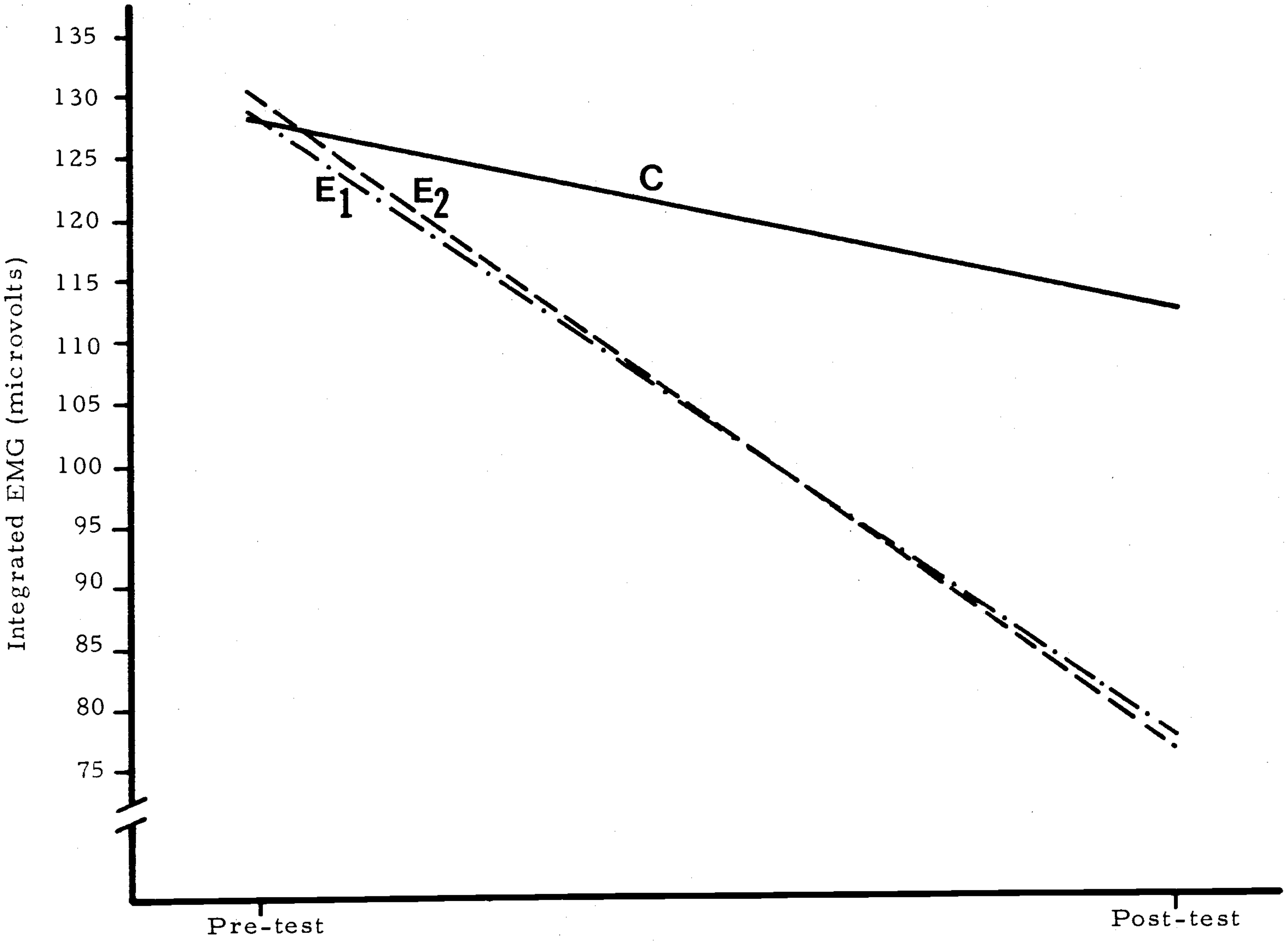

Figure 7. Pre-test to Post-test Group Trends for Integrated EMG Scores in Stabilometer Balancing.

of time-on-target scores, but a significant, difference at the .01 level was found to exist between the integrated EMG group means (Table IV). This outcome was similar to that concluded for the stabilometer balance task. Figure 8 illustrates the pre-test to post-test trends of the three groups for the pursuit-rotor tracking time-on-target scores. Figure 9 represents the integrated EMG group means for the pre-test and post-test for pursuit rotor tracking.

The testing of hypotheses one, two, three, four, seven, and eight were accomplished by analyses of variance. $\underline{F}$ values computed in these analyses were tested for significance. Hypotheses five and six were tested by the computation of $\underline{t}$ values. A summary of these hypotheses, their statistical treatment, and the significance of each is presented in Table V. The testing of each hypothesis will be discussed below following the analysis of the data.

When the analysis of variance of the pre-test and post-test group means of time-on-target scores produced no significant difference, an analysis of variance of the difference scores (i.e., post-test minus pre-test scores within groups) was conducted. Similar tests were run for difference scores in the integrated EMG activity, since correlations were to be conducted throughout after the analyses of variance. Significant differences were found to exist between time-on-target scores by this difference scores method which does not account for the initial differences between the pre-test group means.

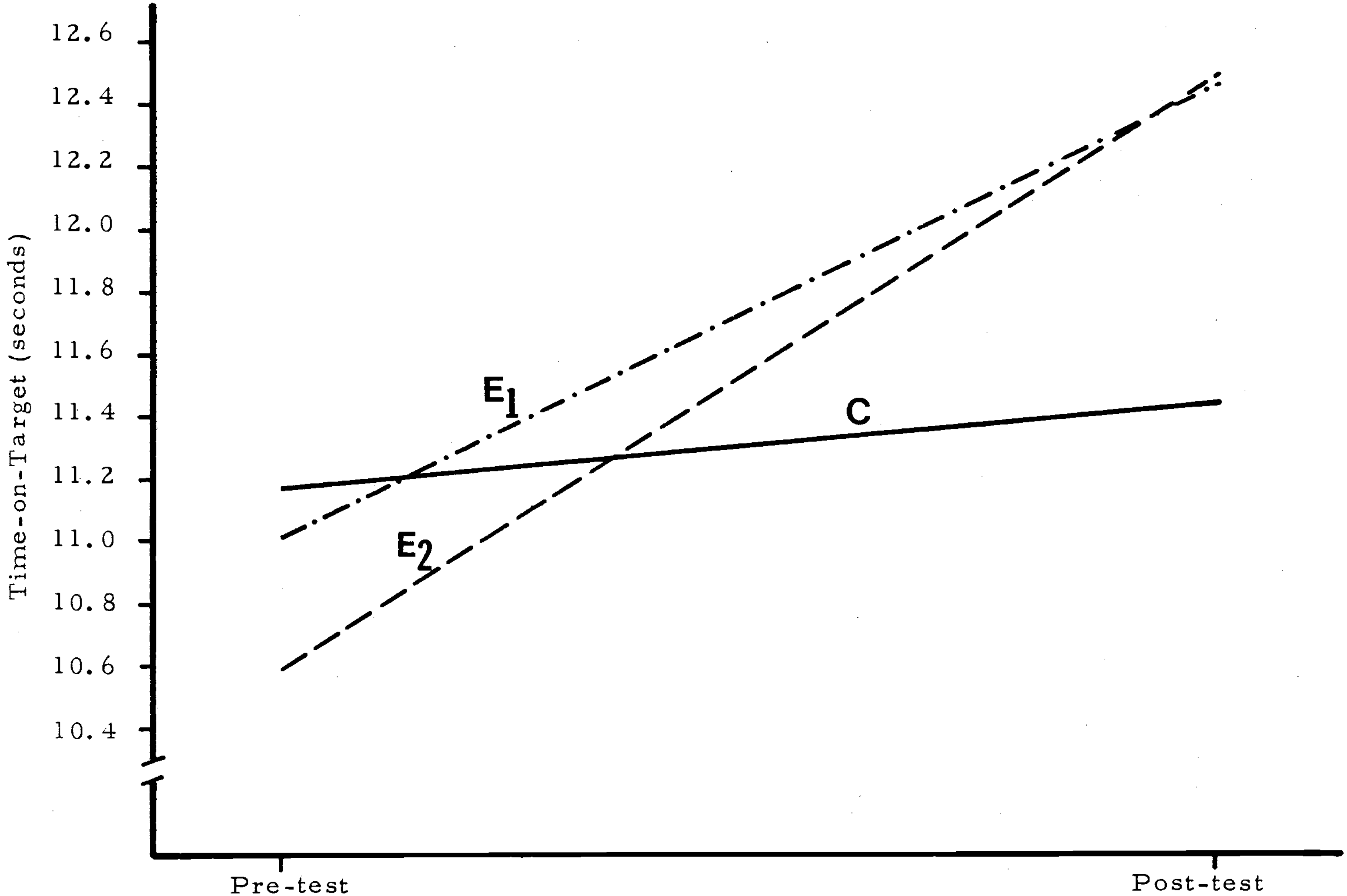

Figure 8. Pre-test to Post-test Group Trends for Time-on-Target Scores in Pursuit-Rotor Tracking.

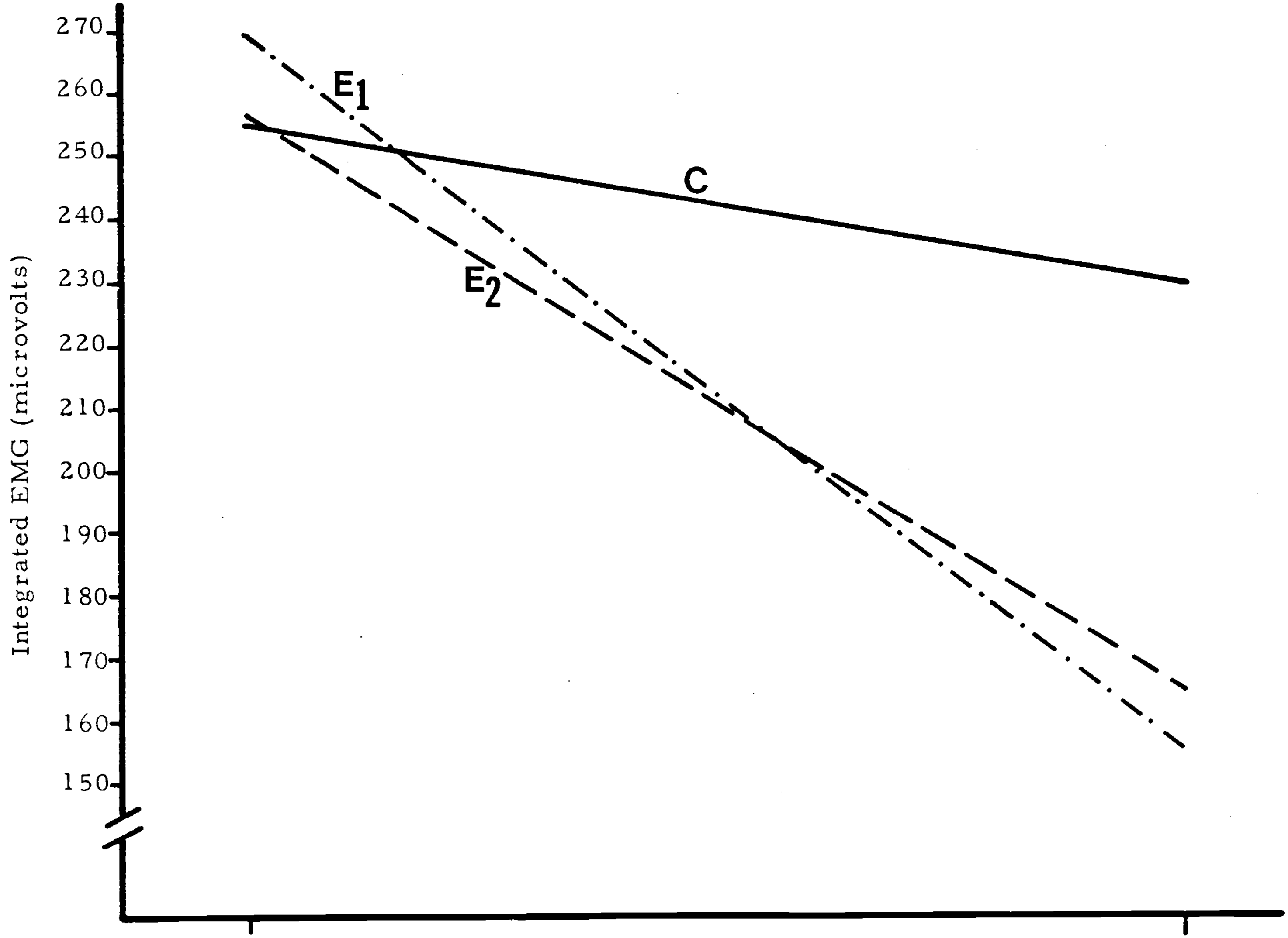

Figure 9. Pre-test to Post-test Group Trends for Integrated EMG Scores in Pursuit-Rotor Tracking.

Table V. Summary of Results of Statistical Testing of Hypotheses.

Hypothesis Number	Comparison Tested	Criterion Instrument	Criterion Measure	L.S.D.	F	Table
1	*E_2 vs C	Stabilometer	Time	.79	2.41	VI
			EMG	37.50	6.27[b]	VI
2	E_2 vs C	Pursuit-Rotor	Time	1.67	7.16[b]	VI
			EMG	65.98	3.46[a]	VI
3	E_1 vs C	Stabilometer	Time	1.26	3.64[a]	VI
			EMG	34.81	6.27[b]	VI
4	E_1 vs C	Pursuit-Rotor	Time	1.18	7.16[a]	VI
			EMG	89.64	3.47[a]	VI
5	Pre-test vs Post-test	Stabilometer	Time	r = .89	t = 1.43	II
			EMG	r = .31	t = 2.74[a]	II
6	Pre-test vs Post-test	Pursuit-Rotor	Time	r = .84	t = 1.09	II
			EMG	r = .27	t = 2.42[a]	II
7	E_1 vs E_2	Stabilometer	Time	.47	2.09	VI
			EMG	2.69	1.38	VI
8	E_1 vs E_2	Pursuit-Rotor	Time	.49	2.11	VI
			EMG	23.66	2.84	VI

[a] Significant at the .05 level   [b] Significant at the .01 level

* Key: E_1 - Experimental group trained in tension control which received auditory feedback during the post-test. E_2 - Experimental group trained in tension control which did not receive auditory feedback during the post-test. C - Control group which performed only the pre-test and post-test.

This result had been predicted by a significant interaction effect produced in the analysis of variance groups by trials completed earlier (Table III).

These findings therefore modify the tests of the hypotheses described above. For example, when the mean difference time-on-target scores were used to re-test hypothesis two, rather than the post-test means analysed above, a significant difference at the .01 level was found between the overall responses of the experimental group which received tension control training, but no auditory biofeedback during post-test performance (E_2), and the control group (C) on the pursuit-rotor tracking task. A significant difference was also computed between the responses of the experimental group which did receive auditory feedback during the post-test (E_1), and the control group (C) when the mean difference time-on-target scores were considered for the pursuit-rotor test (Table VI). A significant difference, therefore, exists when hypothesis four is tested by group mean differences.

One other significant difference was shown to exist by this method. When the mean difference time-on-target scores were used to re-test hypothesis three, a significant difference at the .01 level was found between the overall responses of the experimental group which received augmented feedback on the stabilometer balance post-test (E_2), and the control group (C) (Table VI).

Table VI. Analysis of Post-Test minus Pre-Test Difference Scores.

	STABILOMETER						PURSUIT-ROTOR					
	Time-on-Target			Integrated EMG			Time-on-Target			Integrated EMG		
	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C	E_1	E_2	C
Group Means	1.89	1.42	0.63	50.52	53.22	15.72	1.44	1.93	0.26	114.51	90.85	24.87
E_2 – C					37.50[b]			1.67[b]			65.98[a]	
E_1 – C		1.26[a]			34.81[b]			1.18[a]			89.64[a]	
	L.D.S. (.05) = 1.07			L.S.D. (.01) = 33.03			L.S.D. (.05) = 0.93			L.S.D. (.05) = 62.83		
							L.S.D. (.01) = 1.26					
	F_c = 3.65			F_c = 6.27			F_c = 7.16			F_c = 3.47		
	$F_{.05(2,24)}$ = 3.40			$F_{.01(2,24)}$ = 5.61			$F_{.05(2,24)}$ = 3.40			$F_{.05(2,24)}$ = 3.40		
							$F_{.01(2,24)}$ = 5.61					

[a] Significant at .05 level.

[b] Significant at .01 level.

When pre-test scores were summed and post-test scores were summed for the three groups, an analysis of variance test was applied to determine if overall significant differences existed for the two criterion measures for each of the tasks. A significant difference was found between the pre-test and post-test means of the integrated EMG scores for the stabilometer balance and pursuit-rotor tracking tasks. When the summed scores of the two experimental groups were compared, a significant difference at the .01 level resulted. A comparison of the pre-test and post-test means for the control group revealed no significant difference in either the EMG responses to the stabilometer balancing or the pursuit-rotor tracking tasks. Individually, both experimental group means differed significantly for both tasks. These comparisons, as tested by $\underline{t}$ tests, are listed in Table II.

The only significant difference revealed in this pre-test to post-test comparison with respect to summed time-on-target scores was calculated for Groups E_1 and E_2 for both tasks. However, the failure of the control group to differ significantly between pre-test and post-test means accounts for the fact that no significant difference was found to exist between overall summed means (Table III).

When hypothesis five and hypothesis six were tested by comparing summed group means for the pre-tests and post-tests of the stabilometer balancing task and pursuit-rotor tracking task respectively, significant differences were found to exist with respect to overall integrated EMG scores for both tasks. However, no significant difference exists between overall time-on-target comparisons for the two tests, although significant differences were calculated for the two experimental groups for both tasks (Table II).

The post-test minus pre-test means were compared for the two experimental groups. When time-on-target and integrated EMG scores were analysed for both tasks, no significant difference was found to exist between these two groups (Table VI). Therefore, in testing hypothesis seven, no significant difference appeared between responses of the tension control trained subjects who received feedback during testing and the trained subjects who received no feedback during testing on the stabilometer balancing task. This result held true for both time-on-target and EMG scores. Also, in testing hypothesis eight, no significant difference was found to exist between responses of the tension control trained subjects who received feedback during post-testing and those trained subjects who received no feedback during testing on the pursuit-rotor tracking task. Again, this result held true for both time-on-target performance scores and integrated EMG scores.

Co-efficients of correlation were computed for all concurrent time-on-target and integrated EMG scores, as well as pre-test to post-test correlations of group means. Correlations of time-on-target to EMG scores by trials for pre-tests and post-tests appear in Table VII.

Overall co-efficients of correlation computed by comparing all three groups by all trials for each of the tasks by the pre-tests and post-tests are also tabulated. The correlation co-efficients for time-on-target and EMG scores representing tension manifested concurrently with performance were as follows: stabilometer pre-test (r = -.62), stabilometer post-test (r = -.58), stabilometer balance task, overall (r = -.60); pursuit-rotor pre-test (r = .47), pursuit-rotor post-test (r = .41), pursuit-rotor tracking task overall (r = .45) (Table VII).

Pre-test to post-test correlation co-efficients are tabulated in Table II. The implications of this data will be discussed in the following section, "Interpretation of Data".

Interpretation of Data

The null hypotheses that were developed and tested in this investigation were formulated on the basis of the following research questions:

1. Does electromyographic biofeedback training for tension control produce higher motor performance scores in a gross motor skill test such as the stabilometer dynamic balance test, which evokes high tension levels in an unskilled performer?

Table VII. Co-efficients of Correlation of Time-on-Target to Integrated EMG Scores by Groups by Trials.

	STABILOMETER			PURSUIT-ROTOR		
Trials	E_1	E_2	C	E_1	E_2	C
1	-.54	-.47	-.002	.60	.38	.21
2	-.56	-.65	-.60	.74	.23	.58
3	-.05	-.05	-.57	.76	.39	.18
4	-.41	-.06	-.68	.81	.54	.01
5	-.79	-.30	-.72	.77	.63	.22
6	-.45	-.17	-.44	.92	.71	.11
7	-.35	-.11	-.70	.73	.43	.16
8	-.72	-.12	-.55	.21	.28	.16
9	-.69	-.25	-.84	.21	.38	.11
10	-.74	-.24	-.74	.33	.40	.47
	$\underline{r}$ (pre-test) = -.62[a]			$\underline{r}$ (pre-test) = .47		
		POST-TEST				
1	-.29	-.22	-.40	.37	.02	.61
2	-.20	-.39	-.68	.27	.16	.47
3	-.33	-.70	-.53	.35	.37	.36
4	-.15	-.66	-.37	.09	.46	.32
5	-.60	-.66	-.32	.51	.28	.39
6	-.37	-.56	-.44	.50	.10	.09
7	-.52	-.66	-.23	.26	.24	.10
8	-.65	-.47	-.57	.35	.28	.24
9	-.70	-.41	-.53	.30	.67	.002
10	-.49	-.61	-.48	.48	.20	.14
	$\underline{r}$ (post-test) = -.58[a]			$\underline{r}$ (post-test) = .41		
	$\underline{r}$ (overall) = -.60[a]			$\underline{r}$ (overall) = .45		

[a] Significant linear relationship at .05 level (N = 10).

2. Does electromyographic biofeedback training for tension control produce higher motor performance scores in a fine motor skill test such as the pursuit-rotor tracking test, which evokes high tension levels in an unskilled performer?
3. Does electromyographic biofeedback training for tension control enhance learning by reducing learning time in fine or gross motor activities which induce high tension levels?
4. Does electromyographic auditory biofeedback provided during performance facilitate learning and/or performance of fine or gross motor activities?
5. Do subjects trained in tension control respond similarly to fine and gross motor activities which evoke similarly high tension levels?
6. What relationship exists between the performance score of a fine and/or gross motor test and the tension levels manifested during performance?
7. When electromyographic biofeedback training for tension control is used to reduce general muscular tension with no specific training for a specific fine or gross motor activity, how much transfer of tension control training occurs during the performance of a specific activity?
8. Since some learning will occur between one performance and the next of a novel motor activity, what part of that learning can be

attributed to normal learning progress, and what part is the direct outcome of electromyographic biofeedback training for tension control?

On the basis of the above questions, the following hypotheses were developed and have been tested for significance.

Null hypothesis one, involving the stabilometer balancing task, required the comparison of group means (for both criterion measures) for the experimental group which received tension control training, but no auditory feedback during post-test performance, and the control group. This hypothesis was accepted on the basis of a post-test minus pre-test mean differences F-test in an analysis of variance when time-on-target scores were considered (Table VI). An earlier comparison of the post-test means of these two groups for performance scores also failed to produce a significant difference (Table IV). However, when stabilometer balance integrated EMG scores were compared for these two groups, a significant difference at the .01 level was found to exist. This finding held true for both mean difference comparisons and post-test comparisons (Tables IV and VI). Therefore, with respect to integrated EMG scores representing tension levels during performance, hypothesis one was rejected.

Null hypothesis two stated that, in the pursuit-rotor task measured for time-on-target scores and integrated EMG scores, no significant difference exists between responses of the subjects trained in tension control and not supplied with feedback during post-testing, and a control group. This hypothesis was rejected for both criterion measures. Pre-test minus post-test mean differences of these two groups were compared in an analysis of variance. A difference in time-on-target scores significant at the .01 level was calculated between the EMG means (Table VI). No significant difference resulted between post-test means of these two groups in an earlier analysis (Table IV).

Hypotheses one and two, therefore, compared the pre-test--post-test differences for time-on-target and EMG scores in the stabilometer balancing test and the pursuit-rotor tracking test respectively. The two groups compared were the experimental group which received tension control training and the control group. The only difference which was not significant was the stabilometer time-on-target scores. The mean improvement for the experimental group in this test was 1.42 seconds compared with 0.63 seconds for the control. For the pursuit-rotor task, the experimental group improved 1.93 seconds compared with 0.26 for the control group, a significant difference at the .01 level (Table VI). Integrated EMG scores were compared by post-test means resulting in a significant difference at the .01 level (Table IV), while a comparison of mean differences produced a significant difference at the .05 level (Table VI).

Hypotheses three and four were designed to test the second experimental group; that is, the group that was trained in tension control and did receive auditory feedback during post-testing, and the control group. Hypothesis three was concerned with the stabilometer balancing and was tested with both criterion measures. The hypothesis was rejected for time-on-target and integrated EMG scores which revealed that a significant difference did exist between the responses of the two groups when post-test minus pre-test mean difference scores were analysed (Table VI). An analysis of the post-test time-on-target scores had produced no significant difference between these two groups (Table IV). Therefore, the difference in pre-test means for these two groups, although not significant, was sufficient to hide the true main effect of pre-test to post-test improvement (Table I).

Null hypothesis four, in comparing the time-on-target and EMG scores for the same two groups (E_1 and C) on the pursuit-rotor task, was also rejected for both criterion measures. The trained experimental group which received feedback during post-testing produced performance scores and EMG scores significantly different from those of the control when mean difference scores were compared. Therefore, these two groups were significantly different in their responses to both the fine and gross motor activities (Table VI).

The fifth hypothesis required testing for a significant difference between the responses of subjects in the stabilometer balancing task to pre-test and post-test conditions. Pre-test to post-test correlations and *t* values were calculated for these comparisons. When the three groups were considered as one unit, so that the mean of all pre-test scores of time-on-target were compared with all post-test scores, hypothesis five was accepted. However, a significant difference existed when summed EMG scores were compared (Table II). When these pre-test to post-test correlations were computed for the experimental groups, both combined and individually, a significant difference resulted for both criterion measures. Therefore, the lack of a significant difference between the summed pre-test and summed post-test time-on-target scores can be attributed to the control group's failure to improve significantly. A significant difference at the .01 level was computed between the EMG scores of the summed and individual experimental groups for the stabilometer balance (Table II). Hypothesis five was rejected when overall pre-test and post-test integrated EMG scores were compared.

Hypothesis six was designed to compare the overall pre-test--post-test differences on the pursuit-rotor task. The results were similar to those of the stabilometer task. When the three groups were combined for comparisons of pre-test versus post-test of time-on-target scores, hypothesis six was accepted due to the lack of a significant difference between means. However, when these pre-test to post-test correlations were computed for the experimental groups, both combined and individually, a significant difference was found. Hypothesis six was rejected when EMG scores were summed for the three groups and compared, since the difference between the experimental groups was so large that the small difference for the control group was overcome (Table II).

Hypotheses five and six were accepted for time-on-target scores when overall means, including the control group, were compared to see whether a significant improvement had taken place between the pre-test and post-test trials on the stabilometer balance and pursuit-rotor tracking activities respectively. When the two experimental groups only were summed, in both tasks, a significant difference was found to exist for this comparison. The three groups tested individually for pre-test to post-test correlation produced no significant difference for the control group, but a significant difference did exist between pre-test and post-test scores for each of the experimental groups (Table II).

Hypothesis five and six were rejected for integrated EMG scores when overall means were compared. The only comparisons of pre-test and post-test scores which were not significant were the control group comparisons for the fine and gross motor tasks. A more complete interpretation of these results appears below in the discussion of correlation. Hypothesis seven, which stated that no significant difference exists between responses of the tension control trained subjects who received feedback during testing and those trained subjects who received no feedback during testing on the stabilometer balancing task, was accepted. The post-test minus pre-test means were compared for time-on-target and EMG scores. Neither criterion measure varied significantly between groups.

Hypothesis eight, which involved the same group comparison for the pursuit-rotor tracking task, was also accepted. Neither time-on-target nor EMG scores varied significantly between the experimental groups (Table VI).

A summary of the eight hypotheses and the outcomes of their tests appears in Table V.

A relationship between the concurrent time-on-target scores and integrated EMG scores appears to arise from the outcomes of the tested hypotheses. Before drawing conclusions about these apparent relationships, co-efficients of correlation were computed for all concurrent time-on-target and integrated scores (Table VII), as well as pre-test to post-test correlations of group means (Table II). Correlation co-efficients of time-on-target to EMG scores by groups by trials for pre-tests and post-tests for both motor tasks appear in Table VII. Overall co-efficients of correlation computed by comparing all three groups by trials are also tabulated. The correlation co-efficients for time-on-target and EMG scores representing tension manifested concurrently with performance were as follows: stabilometer pre-test (_r_ = -.62), stabilometer post-test (_r_ = -.58), stabilometer balance test overall (_r_ = -.60); pursuit-rotor pre-test (_r_ = .47), pursuit-rotor post-test (_r_ = .41), pursuit-rotor tracking task overall (_r_ = .45) (Table VII).

In order to determine whether performance and learning are related to the degree of tension manifested during performance of a novel motor activity, the following factors must be considered: 1. A negative correlation appears between these criteria for stabilometer balancing, while a positive correlation appears for pursuit-rotor tracking. 2. Lippold (1957) reported a correlation of .93 to .99 between muscle tension and integrated EMG activity. His findings were corroborated by many investigators. 3. Analyses of the data proposed in hypotheses two, three, four, five, six, seven, and eight, with the exclusion of only hypothesis one, produced corresponding trends (i.e., acceptance or rejection of the hypothesis) for both time-on-target scores and corresponding EMG scores. 4. The co-efficient of correlation of time-on-target and EMG scores for the stabilometer balance task overall was -.60. 5. The co-efficient of correlation of the two scores for the pursuit-rotor tracking task overall was .45.

The criterion measure of integrated EMG scores has been generally assumed to represent tension level manifested during the performance of an activity. This assumption is the basis of all electromyographic biofeedback study of tension, and is supported by researchers in the field as established by Lippold (1957). Nidever (1960) and Eason (1963) found the frontalis muscle to be an excellent indicator of general muscular tension. The time-on-target scores have been generally assumed to represent motor performance of the specific task. No attempt has been made to relate motor performance of the specific criterion tests to any measure of motor ability or motor educability.

As reported in the review of the literature, numerous investigations have been devoted to the study of the influence of induced tension on motor performance. In general, the findings parallel those of verbal-tension, mental-tension comparisons. Some tasks, usually the less complex, have been facilitated by tension, but others, the more complex, are usually inhibited. When the positive correlation between performance and tension for pursuit-rotor tracking is analysed, tension increasing with performance appears to support the claim that simple tasks are facilitated by induced tension. A large portion of the induced tension measured by the electromyograph during performance of the tracking test appears to be induced by eye movement. Since eye movement was continuous and constant during tracking, the remaining portion of the EMG reading, including all increases and decreases, related directly to general muscular tension. However, a significant decrease in tension and increase in performance were found to have occurred as the result of tension control training for the tracking task (hypothesis 6) (Table II). Therefore, although a tension increase accompanied improved performance for both pre-test and post-test conditions of the pursuit-rotor test, the tension-performance relationship was modified by tension control training. In other words, a significant decline in tension between pre-testing and post-testing occurred as the direct result of tension control training. Associated with this was a significant increase in performance. Therefore, for a given situation, under a given set of conditions, induced tension increases accompany improved performance. When training for tension control is imposed upon these conditions, the relationship of tension and performance may be modified to produce improved performance under less tension. Ghisseli (1936) supported this conclusion with his discovery that tension tended to decrease as an individual learned a visual-motor task. Eason (1963) found that improvement in performance was recorded on a tracking task while muscular tension, measured in the neck muscles, remained the same.

When the negative correlation between performance and tension for stabilometer balancing is analysed, the tension reduction which accompanied improved performance appears to support the claim that performances of more complex tasks are inhibited by tension. Training that reduced tension transferred not only to the performance of the simple pursuit-rotor tracking task, but also to the more complex gross motor balancing skill. Significant improvements in performance for both experimental groups in both tasks were accompanied by concurrent significant reductions in tension level. The control group produced no significant difference in either of the motor tasks for either of the criterion measures. The research of Russell (1932), Freeman (1937), Martens (1971), and Berger and Mathus (1969) supports this conclusion that motor performance improves as tension is reduced. Stroud (1931), Daniel (1939), Ghisseli (1936), Eason (1963), Benson (1958) and Paben and Rosentsweigh (1971) all reported a positive relationship between motor learning and a reduction of tension.

Several hypotheses have been advanced to explain tension-performance-learning relationships. Some investigators suggested that the constancy of kinesthetic stimuli as the result of tension raises the level of recruitment and facilitation in all muscle groups through cortical stimulation. Should this theory indeed have foundation, then relaxation or tension control of a particular muscle, e.g., the frontalis, mediated through the cortex, should bring about concomitant tension reduction throughout the body. Freeman (1933), on the other hand, first proposed that muscular tension levels, when increased, lowered the threshold of excitability in the higher nervous centres and, as a result, accurate complex performance may be inhibited.

More recent investigations by Pinneo (1961) and Kempe (1956) indicated relationships between muscular tension and more basic neurological and physiological measures. Pinneo concluded that "proprioceptive return from induced muscular tension produces generalized behavioural and physiological effects in the reticular activating system" (1961). The relationship of tension to total behaviour therefore appears to be a function of the amount of tension induced, the unique characteristics of the nervous system of the individual, and the locale in which induced tension occurs.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Precise, co-ordinated movements are the products of refined motor unit innervation of agonist muscles with reciprocal inhibition of appropriate motor units of the antagonist muscles. Motor unskilled persons display tension levels in agonist and antagonist muscles which exceed any normal level required for correct movement. This presence of residual tension causes one, in effect, to "work against oneself". Reduction of general tension levels during motor performance has been shown to improve performance and learning significantly. Recent advances in electronic technology and biofeedback research have produced a technique known as electromyographic biofeedback. Signals of tension emitted directly by the muscles are amplified and fed back to the subject to augment natural kinesthetic perception. By raising these signals to a level of consciousness, subjects may recognize subtle patterns of tension of which they are normally unaware, and unconsciously learn to recognize these sensations without the aid of the "augmented" feedback. Such is the nature of biofeedback training for tension control.

The purpose of this investigation was to analyse the effects of electromyographic biofeedback for tension control on the acquisition of fine and gross motor skills. Several research questions were induced by the nature of the implications of tension control training on performance and by the fact that electronic biofeedback for residual tension reduction had not previously been applied to motor performance and motor learning studies. On the basis of these research questions, eight null hypotheses were developed and tested.

Experimental Equipment

Specific equipment designed for relaxation training and therapy, as well as standard motor performance testing apparatus were used in this investigation. A BFT 401C feedback myograph and a BFT 215C digital time period integrator were used to monitor and measure muscle tension. A stabilometer, pursuit-rotor machine, and electronic timers provided time-on-target scores as measures of motor performance.

Experimental Procedures

Thirty young adult male Oregon State University student volunteers served as subjects. All were tested for motor performance scores and tension scores on a stabilometer dynamic balance test and a pursuit-rotor tracking test. On the basis of the means of 10 trials on each test, identical triplets were formed and one subject of each triplicate was assigned to one of three groups in a randomized sequence. Analysis of variance tests established that no significant difference in performance mean scores existed between groups. Two of the three groups were then randomly chosen to undertake tension control training, administered for ten half-hour sessions over a period of three weeks. All groups were then re-tested on the same motor tasks. One of the two trained groups received feedback during this post-test.

Analyses of the Data

An analysis of variance groups by trials design was used to test all but two of the eight null hypotheses. Hypotheses five and six were submitted to T-tests with *t* values computed in a pre-test to post-test correlation analysis. All hypotheses were tested for both criterion measures, performance and tension. Co-efficients of correlation were computed for all concurrent means of performance and tension scores, including pre-test to post-test and group-to-group correlations. The .05 level of significance was chosen for rejection of the null hypothesis.

Conclusions

The following conclusions, based upon the test design and analysis of the hypotheses, are evidenced by this investigation. Table V presents a summary of these conclusions.

1. No significant difference existed between the performance responses of subjects trained in tension control and untrained subjects to a stabilometer balancing task. When tension responses were considered, a significant difference did exist between these two groups.

2. A significant difference did exist between responses of subjects trained in tension control and untrained subjects to a pursuit-rotor tracking task for performance and tension.

3. A significant difference did exist between responses of subjects trained in tension control and untrained subjects to a stabilometer balancing task when the trained subjects were provided auditory biofeedback during post-training performance. This difference existed for both criterion measures.

4. A significant difference did exist between responses of subjects trained in tension control and untrained subjects to a pursuit-rotor tracking task when the trained subjects were provided auditory biofeedback during post-training performance. Again, both criterion measures were significantly different between the two groups.

5. A significant difference did exist between tension responses of subjects to the stabilometer balancing task between pre-testing and post-testing. The difference between means of the performance scores was not significant. Further scrutiny revealed that the trained subjects'

means varied significantly. The failure of the control group performance means to do so caused the lack of a significant difference.

6. As for hypothesis five, a significant difference did exist between tension scores but not between overall means of performance scores on the pursuit-rotor task between pre-testing and post-testing. However, the trained groups produced a significant performance difference.

7. No significant difference existed between responses of the trained subjects who received feedback during testing and those trained subjects who did not receive feedback during testing on the stabilometer balance task. This effect was true for performance and tension scores.

8. No significant difference existed between responses of the trained subjects who received feedback during testing and those trained subjects who received no feedback during testing on the pursuit-rotor tracking task. This effect was also true for both criterion measures.

A negative co-efficient of correlation of -.60 was computed for the performance-tension relationship on the stabilometer balancing task. A positive co-efficient of correlation of .45 was found to describe the performance-tension relationship on the pursuit-rotor tracking task.

Recommendations

The outcome of this investigation suggests many possibilities for related research in the area of biofeedback tension control training effects on motor performance and motor learning. Alternative delimitations to those of this study provide additional research considerations.

1. The influence of tension control training by electromyographic biofeedback on other exercise variables might be investigated. Anticipation before tension-inducing events may be detrimental to performance, especially when maximum conservation of energy sources is required. The training effect of tension reduction by biofeedback should be tested on the sports field, in the examination room, in the controller's seat of space vehicles, and in everyday situations that evoke physiological and psychological stresses upon the individual.

2. The scores in both criterion measures for the trained group which did receive feedback during the post-tests were consistently higher than those of the trained group which didn't receive feedback during the post-tests. None of the between-test training was designed to assist either group to attend to feedback during performance. Therefore, a reasonable assumption may be made that, should a group trained in resting tension control be provided more training with biofeedback during performance, its performance may be

enhanced over a group which does not receive biofeedback training during activity.

3. Replicated studies using low motor ability groups versus high motor ability groups may produce different results. No attempt was made in this study to compare ability level responses to biofeedback training.

4. A replicated study using a younger or older age group may produce evidence on proprioceptive trainability.

5. Replication of this study using female subjects may produce significantly different results, since female strength and balancing ability differences may influence tension levels induced by gross motor activity.

REFERENCES

Adams, J. A. Response feedback and learning. Psychological Bulletin, 70:486-504, 1968.

Adams, J. A. A closed-loop theory of motor learning. Journal of Motor Behavior, 3:111-149, 1971.

Adrian, E. D. and D. W. Bronk. The discharge of impulses in motor nerve fibres. Part I. Impulses in single fibres of the phrenic nerve. Journal of Physiology, 66:81-101, 1928.

Adrian, E. D. and D.W. Bronk. The discharge of impulses in motor nerve fibres. Part II. The frequency of discharge in reflex and voluntary contractions. Journal of Physiology, 67:119-151, 1929.

Adrian, E. D. and Y. Zotterman. The impulses produced by sensory nerve endings. Part 2. The response of a single end-organ. Journal of Physiology, 61:151-171, 1936.

Ashworth, B., L. Grimby and E. Keigelberg. Comparison of voluntary and reflex activation of motor units: functional organization of motor neurones. Journal of Neurology and Neurosurgery in Psychiatry, 30:91-98, 1967.

Bachman, J. C. Motor learning and performance as related to age and sex in two measures of balance co-ordination. Research Quarterly, 32:123-137, 1961.

Baker, D. Symposium on muscle receptors. Hong Kong University Press. Hong Kong, 1948.

Basmajian, J. V. Control and training of individual motor units. Science, 141:440-441, 1963.

Basmajian, J. V. Muscles Alive, Their Functions Revealed by Electromyography. William and Wilkins, Baltimore, 1974.

Basmajian, J. V., M. Baeza, and C. Fabrigar. Conscious control and training of individual spinal motor neurons in normal human subjects. Journal of New Drugs, 5, 78-88, 1965.

Bass, R. I. An analysis of the components of tests of semi-circular canal function and of static and dynamic balance. Research Quarterly, 10:35-52, 1939.

Begbie, G. H. The effects of alcohol and of varying amounts of visual information on a balancing test. Ergonomics, 9:325-333, 1966.

Benson, D. Effects of concomitant learning in relaxation and swimming improvement. Unpublished study, University of California, Los Angeles, California, 1958.

Berger, R. A. and D. L. Mathus. Movement time with various resistance loads as a function of pre-tensed and pre-relaxed muscular contractions. Research Quarterly, 40:456-459, 1969.

Berry, C. M., R. C. Karl, and J. C. Hinsey. Course of spino-thalamic and medial lemniscus pathways in cat and rhesus monkey. Journal of Neurophysiology., 13:149-156, 1950.

Bilodeau, E. A. Retention. In E. A. Bilodeau (Ed.) Acquisition of Skill. Academic Press, New York, 1966.

Boyd, I. A. The histological structure of the receptors in the knee joint of a cat correlated with their physiological responses. Journal of Physiology, 124:469-488, 1954.

Breinin, G. M. Electromyographic evidence for ocular proprioception in man. Arch. Opthal., 57:176-180, 1957.

Budzynski, T., J. Stoyva and C. Adler. Feedback-induced muscle relaxation: Application to tension headache. Behavior Therapy and Experimental Psychiatry, 1:205-211, 1970.

Budzynski, T and J. Stoyva. Biofeedback techniques in behavior therapy and autogenic training., Manuscript: University of Colorado Medical Center, 1971.

Bugelski, B. R. The Psychology of Learning. Holt, Rinehart and Winston, New York, 1956.

Cason, H. and M. A. Trowbridge. An experimental study of Thorndike's theory of learning. Journal of Genetic Psychology, 7:245-260, 1932.

Cooper, S. The responses of the primary and secondary endings of muscle spindles with intact motor innervation during applied stretch. Quarterly Journal of Experimental Physiology, 46: 389-398, 1961.

Cratty, B. J. Movement Behavior and Motor Learning, (3rd Edit.) Lea and Febiger, Philadelphia, 1973.

Cron, G. W. and N. H. Pronko. Development of the sense of balance in school children. Journal of Educational Research, 51:33-57, 1957.

Daniel, R. S. The distribution of muscular action potentials during maze learning. Journal of Experimental Psychology, 24:621-629, 1939.

Davis, R. C. The relation of certain muscle action potentials to "mental work", Bloomington, Ind., Indiana University Publication, Science Series, 5, 1937.

De Vries, H. A. Physiology of Exercise for Physical Education and Athletics. (2nd edition), Wm. C. Brown, Co., Dubuque, Iowa, 1974.

Dickinson, J. The training of mobile balancing under a minimal visual cue situation. Ergonomics, 11:69-75, 1968.

Duffy, E. Activation and Behavior. New York, John Wiley and Sons, Inc., 1962.

Eason, R. G. Relation between effort, tension level, skill and performance efficiency in a perceptual-motor task. Perceptual Motor Skills, 16:525-543, 1963.

Eccles, J. C. Circuits in the cerebellar control of movement. Proceedings of the National Academy of Sciences. 58:336-343, 1967.

Edwards, A. L. Experimental Design in Psychological Research, Holt, Rinehard and Winston, New York, 1960.

Edwards, A. S. Body sway and vision. Journal of Experimental Psychology, 36:526-535, 1946.

Eldred, E., R. Granit and P. A. Merton. Supraspinal control of the muscle spindles and its significance. Journal of Physiology. 122:498-523, 1953.

Erlanger, J. and H. S. Gasser. Electrical signs of nervous activity. Johnson Foundation Lectures. University of Pennsylvania Press, Philadelphia, 1937.

Espenschade, A., R. R. Dable and R. Schoendaube. Dynamic balance in adolescent boys. Research Quarterly, 24:270-275, 1953.

Fearing, F. S. The factors influencing static equilibrium. Journal of Comparative Psychology, 8:95-112, 1924.

Fitts, P. M. Engineering psychology and equipment design. In S. S. Stevens (Ed.), Handbook of Experimental Psychology, Wiley, New York, 1951.

Fitts, P. M. Perceptual motor skill learning. In A. W. Melton (Ed.) Categories of Human Learning. Academic Press, New York, 1964.

Fitts, P. M., and M. I. Posner. Human Performance. Brooks/Cole Publishing Co., Belmont, California, 1967.

Fleishman, E. A. The structure and measurement of physical fitness. Prentice-Hall, New Jersey, 1964.

Fleishman, E. A., and W. E. Hempel. Factorial analysis of complex psychomotor performance and related skills. Journal of Applied Psychology, 40:96-104, 1956.

Fleishman, E. A., and S. Rich. Role of kinesthetic and spatial visual abilities in perceptual motor learning. Journal of Experimental Psychology, 66:6-11, 1963.

Freeman, G. L. Facilitative and inhibitory effects of muscular tension upon performance. American Journal of Psychology, 45:17-52, 1933.

Freeman, G. L. Studies in the psycho-physiology of transfer: I. The problem of identical elements. Journal of Experimental Psychology, 2:521, 1937.

Gaarder, K. Control of states of consciousness, Parts I and II. Archives of General Psychiatry, 25:429-435; 430-441, 1971.

Gagne, R. M., and E. A. Fleishman. Psychology and Human Performance. Holt and Co., New York, 1959.

Gardner, E. Physiology of moveable joints. Physiology Review, 30:127-176, 1950.

Gardner, E. and B. Haddad. Pathways to the cerebral cortex for afferent fibres from the hindleg of the cat. American Journal of Physiology, 172:475-482, 1953.

Gellhorn, E. The influence of alterations in posture of the limbs on cortically induced movements. Brain, 71:26-33, 1948.

Gernandt, B. E. Vestibular connections in the brainstem. In M. B. Bender (Ed.), The Oculomotor System. Harper and Row, New York, 1964.

Ghisseli, E. Changes in neuromuscular tension accompanying the performance of a learning problem involving constant choice of time. Journal of Experimental Psychology, 19:91-98, 1936.

Gibbs, C. B. The continuous regulation of skilled response by kinesthetic feedback. British Journal of Psychology, 45:24-39, 1954.

Gibbs, C. B. Servo control systems in organisms and the transfer of skill. In D. Legge (Ed.) Skills. Harmondsworth: Penguin Books, 1970.

Goetzinger, C. P. The re-evaluation of the Heath Railwalking Test. Journal of Educational Research, 54:187-191, 1961.

Goldstein, J. B. Role of muscle tension in personality theory. Psychology Bulletin, 61:413-425, 1964.

Granit, R. Receptors and Sensory Perception. Yale University Press, New Haven, 1955.

Granit, R. and B. R. Kaada. Influence of stimulation of central nervous structures on muscle spindles in cat. Acta Physiologica Scandinavica, 27:130-150, 1952.

Graybiel, A., and A. R. Frogly. A new quantitative ataxia test battery. H.A.S.A. Joint Report, 1965.

Green, E. E., A. M. Green and E. D. Walters. Voluntary control of internal states: psychological and physiological. Journal of Transpersonal Psychology. 2:1-26, 1970.

Green, E. E., E. D. Walters, A. M. Green and G. Murphy. Feedback techniques for deep relaxation. Psychophysiology, 6:371-377, 1969.

Grimby, L. and J. Hannerz. Recruitment order of motor units on voluntary contraction: changes induced by proprioceptive afferent activity. Journal of Neurology and Neurosurgery in Psychiatry, 31:565-573, 1968.

Grimby, L. and J. Hannerz. Differences in recruitment order of motor units in phasic and tonic flexion reflex in 'spinal man'. Journal of Neurology and Neurosurgery in Psychiatry, 33:502-570, 1970.

Grossman, S. P. A Textbook of Physiological Psychology. Wiley and Sons, Inc., New York, 1967.

Guthrie, E. R. The Psychology of Learning. Harper and Row. New York, 1952.

Guthrie, E. R. Association by contiguity. In S. Koch (Ed.), Psychology: A Study of Science, Vol. 2. McGraw-Hill, New York, 1959.

Hayes, K. J. Wave analyses of tissue noise and muscle action potentials. Journal of Applied Physiology, 15:749-752, 1960.

Hellebrandt, F. A., G. Brown and R. H. Zepper. The relation of the centre of gravity to the base of support in stance. American Journal of Physiology, 19:313-332, 1937.

Henneman, E., G. Somjen and D. O. Carpenter. Excitability and inhibitibility of motoneurons of different sizes. Journal of Neurophysiology, 28:599-620, 1965.

Hilgard, E. R., and G. H. Bower. Theories of Learning. (3rd edit.) Appleton-Century-Crofts. New York, 1966.

Holding, D. H. Principles of Training, Pergamon Press, Oxford. 1965.

Holding, D. H., and A. W. Macrae. Rate and force of guidance in perceptual motor tasks with reversed or random spatial correspondence. Ergonomics, 9:289-296, 1964.

Howard, I. P. Motor system. In J. A. Deutsch and D. Deutsch (Eds.) Physiological Psychology. The Dorsey Press, Homeward, Ill., 1966.

Howard, I. P. and W. B. Templeton. Human Spatial Orientation. Wiley, New York, 1966.

Hull, C. L. A Behaviour System. John Wiley and Sons, Inc. New York, 1952.

Hunt, C. C. and A. S. Paintal. Spinal regulation of fusimotor neurones. Journal of Physiology, 143:195-212, 1958.

Jacobson, E. Progressive Relaxation. University of Chicago Press, Chicago, 1938.

Kempe, J. E. An experimental investigation of the relationship between certain personality characteristics and physiological responses to stress in a normal population. Doctoral dissertation, Michigan State University, East Lansing, Michigan, 1956.

Kerr, W. H., and J. D. Weinlund. Muscular perceptivity as a trade test. Journal of Applied Psychology, 17:550-558, 1933.

Koerthe, W. A. A pursuit apparatus: eye-hand co-ordination. Psychology Monographs, 31:288-292, 1922.

Leonard, J. A. Static and mobile balancing in blind children. Bulletin of the British Psychological Society, 19:63, A24 (abstract), 1966.

Leonard, S. D., E. W. Karnes, J. Oxendine and J. Hesson. Effects of task difficulty on transfer performance on rotary pursuit. Perceptual and Motor Skills, 30:731-736, 1970.

Lippold, O. C. J. The relation between integrated action potentials in the human muscle and its isometric tension. Journal of Physiology, 117:492-499, 1952.

Lloyd, A. J., and L. S. Caldwell. Accuracy of active and passive positioning of the leg on the basis of kinesthetic cues. Journal of Comparative and Physiological Psychology, 60:102-106, 1965.

Lordahl, D. S. Effect of the weight-contrast illusion on rotary pursuit performance. Perceptual and Motor Skills, 17:87-90, 1963.

Malmo, R. Emotion and muscle tension. Psychology Today, 64-67, March, 1970.

Marteniuk, R. G. Motor performance and induced muscular tension. Research Quarterly, 39:1025-1031, 1969.

Martens, R. Anxiety and motor behavior: a review. Journal of Motor Behavior, 3:151-179, 1971.

Mathews, A. M. and M. G. Gelder. Psycho-physiological investigations of brief relaxation training. Journal of Psychosomatic Research, 13:1-12, 1969.

Matthews, B. H. C. The response of a muscle spindle during active contraction of a muscle. Journal of Physiology. 72:153-174, 1931.

Matthews, B. H. C. Nerve ending in mammalian muscle. Journal of Physiology, 78:1-53, 1933.

Miles, W. R. Static equilibrium. In R. W. Gerard (Ed.), Methods in Medical Research, Vol. 3, Yearbook Publishers, Chicago, 1950.

Moruzzi, G. Problems in Cerebellar Physiology. Thomas, Springfield, Ill., 1950.

Mountcastle, V. B. Modality and topographic properties of single neurons of cat's somatic sensory cortex. Journal of Neurophysiology, 20:408-434, 1957.

Mountcastle, V. B., G. F. Poggio and G. Werner. The relation of thalamic cell response to peripheral stimuli varied over an intensive continuum. Journal of Neurophysiology, 26:804-834, 1963.

Mowrer, O. H. On the dual nature of learning. A reinterpretation of 'conditioning' and 'problem solving'. Harvard Educational Review, 17:102-148, 1947.

Mowrer, O. H. Learning Theory and Behavior. Wiley, New York, 1960.

Mumby, H. H. Kinesthetic acuity and balance related to wrestling ability. Research Quarterly, 24:327-330, 1953.

Myer, D. R. and M. E. Noble. Summation of manifest anxiety and muscular tension. Journal of Experimental Psychology, 55: 599-602, 1958.

Nidever, J. E. A factor analytic study of general muscular tension. Doctoral dissertation, University of California, Los Angeles, California, 1960.

Olsen, C. B., D. O. Carpenter and E. Henneman. Orderly recruitment of muscle action potentials: motor unit threshold and EMG amplitude. Archives of Neurology, 19:591-597, 1968.

Oscarsson, O. The projection of Group 1 muscle afferents to the cat cerebral cortex. In R. Granit (Ed.), Muscular Afferents in Motor Control, Wiley and Sons, New York, 1966.

Paben, M. and J. Rosentweigh. Control of muscular tension in learning a novel gross motor skill. Perceptual Motor Skill, 32:556-558, 1971.

Paillard, J. The patterning of skilled movements. In J. Field, H. W. Magoun and V. E. Hall (Eds.) Handbook of Physiology, Section 1, Volume 3. Washington. American Physiological Society, 1960.

Phillips, B. E. The relation between certain phases of kinesthesis and performance during the early stages of acquiring two perceptuo-motor skills. Research Quarterly, 12:571-586, 1941.

Phillips, M., and D. Summers. Relation of kinesthetic perception to motor learning. Research Quarterly, 25:456-469, 1954.

Pinneo, L. R. The effects of induced muscular tension during tracking on level of activation and on performance. Journal of Experimental Psychology, 62:523-531, 1961.

Ruch, T. C. Motor systems. In S. S. Stevens (Ed.) Handbook of Experimental Psychology, 16:116-122, 1951.

Ruch, T. C. and H. D. Patton. Physiology and Biophysics. W. B. Saunders Co., Philadelphia, 1965.

Ruch, T. C., H. D. Patton, J. W. Woodbury and A. L. Towe. Neurophysiology, W. B. Saunders Co., Philadelphia, 1963.

Russell, J. T. Relative efficiency of relaxation and tension in performing an act of skill. Journal of General Psychology, 6: 330-343, 1932.

Seashore, H. G. Measurement of dynamic balance with a walking beam test. Psychological Bulletin, 35:714(abstract), 1938.

Seashore, R. H., and A. Bavelas. The function of knowledge of results in Thorndike's linedrawing experiment. Psychological Review, 48:155-164, 1941.

Shultz, J. H. and W. Luthe. Autogenic Training. Grune and Stratton, Inc., New York, 1959.

Slater-Hammel, A. T. Performance of selected groups of male college students on the Reynolds balance tests. Research Quarterly, 27:348-351, 1956.

Smith, K. U. Delayed Sensory Feedback and Behavior, Saunders, Philadelphia, 1962.

Smith, K. U. Cybernetic Theory and Analysis of Learning. In. E. A. Bilodeau, (Ed.), Acquisition of Skill. Academic Press, New York, 1966.

Smith, J. L. Kinesthesis: a model for movement feedback. In R. C. Brown and B. J. Cratty (Eds.) New Perspectives of Man in Action. Prentice-Hall Inc., Englewood Cliffs, 1969.

Sprague, J. M. and W. W. Chambers. Control of posture by reticular formation and cerebellum in the intact, anesthetized and unanesthetized and in the decerebrate cat. American Journal of Physiology, 176:52-64, 1954.

Stroud, J. B. The role of muscular tension in stylus maze learning. Journal of Experimental Psychology, 14:606-631, 1931.

Sumitsuji, N., K. Matsumoto, M. Tanaka, T. Kashiwagi and Z. Kaneko. Electromyographic investigation of the facial muscles, Electromyography, 7:77-96, 1967.

Travis, R. C. A new stabilometer for measuring dynamic equilibrium in the standing position. Journal of Experimental Psychology, 34:418-424, 1944.

Travis, R. C. Experimental analysis of dynamic and static equilibrium. Journal of Experimental Psychology, 35:216-234, 1945.

Thorndike, E. L. The law of effect. American Journal of Psychology, 39:212-222, 1927.

Vitti, M. and J. V. Basmajian. Electromyographic investigation of procerus and frontalis muscles, in press.

Wallon, Evert-Chmielniski and Sauterey. Equilbre statique, equilbre en movvement; double laterijation (entre 5 et 15 ans). Enfance 1:1-29, 1958.

Wenger, M. A. Muscular processes and personality. Child Development, 9:261-276, 1938.

Whatmore, G. B., and D. Kohli. Dysponesis: a neurophysiologic factor in functional disorders. Behavior Science, 13:102-124, 1968.

Wiebe, V. R. A study of tests of kinesthesis. Research Quarterly, 25:222-230, 1954.

Wilson, A. and A. S. Wilson. Psychophysiological and learning correlates of anxiety and induced muscle relaxation. Psychophysiology, 6:740-748, 1970.

Wolpe, J. The Practice of Behavior Therapy. Pergamon Press, New York, 1969.

APPENDIX A

Approval of Use of Human Subjects

OREGON STATE UNIVERSITY

Committee for Protection of Human Subjects

Summary of Review

Title: Electromyographic Biofeedback for Tension Control During Fine and Gross Motor Skill Acquisition

Program Director: Donald E. Campbell (Stephen N. French)

Recommendation:

XX Approval

______ Provisional Approval

______ Disapproval

______ No Action

Remarks:

Date: May 10, 1976

Signature: ____________________

J. Ralph Shay
Assistant Dean of Research
Phone: 754-3437

cc: Dr. MacDonald

mep

APPENDIX B

Letter to Participants

Dear Participant,

Your assistance is needed for an investigation of the effects of tension control training on performance of motor skills. This study will help determine whether or not human performance of movement can be improved when tension is controlled due to relaxation training.

Previous studies indicate that the use of electromyographic biofeedback (information on the degree of muscle tension in the body) has become a reliable method of reducing anxiety and muscle tension in therapeutic and clinical situations. All of us are aware that our performances of mental skills (for example, taking exams) and motor skills (learning to play tennis or ski) are hampered by anxiety or tension, which is reduced by practice or confidence in the job at hand. The purpose of this study is to show that tension control training will provide learners with a means of reducing unwanted tension and improving their learning speed of reasonably complex tasks. The major benefit of such training is that tension control is integral to all aspects of everyday living, and, once learned, is a very valuable skill.

Your participation will involve two one-hour testing sessions of balancing and tracking skills and nine twenty-minute tension control training sessions with the electromyograph, a total of five hours. The testing sessions cause no physical or mental stress that is harmful to the performer. Measurement of tension is attained by small flat electrodes attached to the skin of the forehead with comfortable stickers. The electrodes relay activity of the underlying muscle to the electromyograph for amplification. The sounds of this muscle activity are presented to the subject via headphones so that he can concentrate on reducing the pitch, thereby reducing tension, since this frontalis muscle of the forehead is an excellent indicator of general muscular tension throughout the body.

Your performance scores on the motor skills tests will be treated confidentially.

more . . .

Your help will be greatly appreciated. If you are willing to participate, please complete the acknowledgement form below. Please note that you are free to withdraw your consent and to discontinue participation in the project at any time.

Acknowledgement of Willingness to Participage

The undersigned acknowledges that he will volunteer to take part in the "tension control biofeedback study" being conducted by the Department of Physical Education at Oregon State University.

Name: ______________________________

Phone: ______________________________

Address: ______________________________

Signature: ______________________________ Date: ____________

(Please return this form and retain the letter on page one for your own information.)

APPENDIX C

Demographic Data Form

1. Subject's Name ....
2. Age ...... 3. Height .... 4. Weight .....
5. Academic Major .... 6. GPA .....
7. Present Course Load ..... hrs. 8. Job .... hrs
9. Activity Status (describe your regular physical activity e.g. hours of jogging--high or medium intensity, etc.), IM's, etc.

____

____

Group	______
Init T Sc	______
Pre $\overline{X}$ 1.	______
Post $\overline{X}$ 1.	______
Pre $\overline{X}$ 2.	______
Post $\overline{X}$ 2.	______
Class.	______

10. Are you under pressure academically this term? ☐ Yes/No ☐

    If yes, describe: ______________________________

    ____

11. Are you on prescribed medication (allergens, etc.) ☐ Yes/No ☐

    If yes, how may this drug affect you? ______________________

    ____

12. Do you smoke? ☐ Yes/No ☐ Do you use alcohol or drugs? ☐ Yes/No ☐ If yes, how may these drugs affect you?

    ____

13. Do you feel that you can relax quite easily? ☐ Yes/No ☐

    In comparison with your college-age friends, would you rate yourself as very relaxed ☐, relaxed ☐, slightly tense ☐, moderately tense ☐, tense ☐, extremely tense ☐ ? Please check one.

Thank you for your cooperation. This information will be strictly confidential to me, and used only for classification purposes.

APPENDIX D

Data Recording Form

Date: ____________

Time: ____________

☐ Stabilometer Test

☐ Pursuit-Rotor Test

☐ Pre-Test

☐ Post-Test

S	Initial Tension Level	1	2	3	4	5	6	7	8	9	10	$\overline{X}$
					Trials							
	Tension											
	Time											
	Tension											
	Time											
	Tension											
	Time											