UNIVERSITY OF MANITOBA

THE EFFECTS OF INDUCING LOCALIZED MUSCULAR FATIGUE ON THE PERFORMANCE AND LEARNING OF THE PURSUIT ROTOR TASK

by

Greg A. Meade

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
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ABSTRACT

The purpose of the present investigation was first, and primarily, to determine whether the inverted U model represents the relationship found between fatigue and the performance and learning of a psychomotor task; and, secondly whether a relationship exists between the effects of fatigue on performance and the effect of fatigue on reaction time. Thirty-five college males were randomly assigned to one of five groups; a control or one of four fatigue groups. All subjects were given twenty-eight pursuit rotor trials and twenty-three reaction time trials. Trials one to three were given under non-fatigued conditions and represented the pre-testing values. All subjects then performed two minutes of hand cranking a modified bicycle ergometer, followed by a reaction time trial and a pursuit rotor trial. Subsequent fatigue bouts, interpolated after a reaction time and pursuit rotor trial, lasted for fifteen seconds. The procedure continued until twenty-three trials were completed. Five more pursuit rotor trials were performed after forty-eight hours, in a non-fatigued condition. Resistance on the bicycle ergometer was set at 0%, 25%, 40%, 60% or 80% of a two minute maximum established prior to the testing day.

The results indicated that the main effect of fatigue was not significant among experimental groups. Graphical presentation of the performance data may be interpreted as containing some support for an inverted-U relationship. Learning scores were not significantly affected by fatigue, and no inverted U relationship existed for this variable. The coefficients of the correlation between performance and reaction speed under fatigued conditions were generally low and not significant, and no clear pattern of relationship between these variables emerged.

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CHAPTER 1

INTRODUCTION

The exact nature by which fatigue affects performance and learning has been an area of research within the field of motor learning for a number of years. However, the research has been characterized by a diversity of findings and conclusions. Some studies have shown that fatigue will impair performance but will have no effect upon learning (Carron, 1969; Schmidt, 1969), while others have found fatigue to be detrimental to both performance and learning (Godwin & Schmidt, 1971; Carron & Ferchuck, 1971). An improvement in performance and learning while practising under the influence of fatigue has also been shown (Benson, 1968; Cochran, 1975).

Gutin (1973) has suggested that there exists a relationship between the level of activation and performance and learning. According to Gutin (1973) this relationship is of a curvilinear nature and takes the shape of an inverted U. The inverted U model suggests that as the level of activation increases, performance and learning would improve, up to an optimal point, and then would deteriorate with further increases in the activation. This relationship has been tested by a number of researchers (eg. Williams & Singer, 1975; Pack, Cotten & Biasiotto, 1974) and expanded into an inverted J model by Thomas, Doyice, Spieth and Abraham (1975), but no definitive conclusions have been drawn.

One of the integral components of performance and learning is reaction time. Kroll (1974) has stated that "it is well accepted that skilled performance is highly dependent upon optimum timing and co-ordination of muscular action. Fatigue is presumed to be capable of disrupting and adversely affecting the spatial-temporal aspects of skilled performance" (p. 260). According to Wood (1979), "if the fatigued performer takes longer to process sensory information and affect the appropriate muscular responses, then a breakdown in skilled performance could be expected" (p. 248). One reason performance and learning may be affected by fatigue is the possibility that fatigue has an effect upon reaction time. However, as is the case with research dealing with fatigue and its effect upon performance and learning, studies dealing with fatigue and reaction time exhibit mixed findings.

Earlier studies have pointed towards an inverted U relationship (eg. Levitt & Gutin, 1971; Sheerer & Berger, 1972), while more recent studies have concentrated on pinpointing the exact locus for the manifestation of fatigue by studying fractionated reaction time. Efforts in this direction have met with varying degrees of success.

It becomes evident from the literature that while many studies have dealt with fatigue and its effects, many questions still remain as to the nature of those effects.

Does the inverted U model truly represent the relationship between fatigue and performance and can this model be used to represent the relationship between fatigue and learning? Is there a relationship between fatigue and reaction time and if so, is this relationship similar to what may be found between fatigue and performance and learning? Can the findings related to reaction time be used as a possible explanation of the findings with respect to learning and performance?

Statement of the Problem

The purpose of this study was to investigate whether the inverted U model adequately represents the effects of fatigue upon performance and learning. It was also investigated whether a relationship exists between the effects of fatigue on performance and learning and the effect of fatigue on reaction time.

Delimitations

In developing this study a number of restrictions were placed upon it in an attempt to reduce its complexity. While fatigue may manifest itself as both a psychological and physiological condition, this study dealt with only physiological fatigue. It was the intent of this author to investigate fatigue and its effects upon motor tasks, As a result this study was restricted to the use of a psychomotor task.

It may be that fatigue and its effect is influenced by the sex of the subjects. It was not the interest of this author to investigate any gender-related differences, and as a result only male subjects participated. As well, to protect against differences that may occur between dominant and non-dominant limbs, only right handed males participated.

Limitations

A number of limitations acted upon this study that may have influenced the findings. The subjects that participated in this study were volunteers, and as a result a concern regarding individual motivation may arise. No attempt to measure motivation was made. As well, because of the volunteer nature of the subjects, only thirty-five males participated in the study. The low number of subjects may have influenced the results.

Definition of Terms

Learning: For the purpose of this study, an individual learning score was determined by subtracting the average of trials one-three (mean 1) of pursuit rotor performance from the average of trials 24-28 (mean 6). This difference was defined as the learning score.

Performance: For the purpose of this study, performance was defined as the amount of time recorded on target during a pursuit rotor trial.

Fatigue: In this study fatigue was defined as a localized physiological condition induced by requiring from the subject two minutes of hand cranking a modified bicycle ergometer at a preset cadence, and with a resistance determined on the basis of the subjects maximum output and by the fatigue group assigned to.

Reaction Time: In this study reaction time was the time between the turning on of a switch by the researcher (stimulus) and the subsequent releasing of a switch by the subject (beginning of the response).

Premotor Time: Measured as the time interval between the onset of the stimulus to the beginning of the action potential within the muscle.

Motor Time: Measured as the time interval between the action potential within the muscle and the turning off of a switch.

Reminiscence: The improvement in pursuit rotor scores that occurred from the end of practise to the retest.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The studies investigating fatigue and learning, fatigue and performance and fatigue and reaction time have all attempted to manipulate the activation or fatigue levels of their subjects and then measure their effect upon the different components. Fatigue has been induced by a variety of different physical activities, while performance, learning and reaction time have been measured by using a wide variety of different motor tasks all with the purpose of determining if a possible relationship exists between fatigue and performance and learning.

This chapter has been divided into two sections, which will review the literature pertaining to fatigue and performance and learning, and to fatigue and reaction time and which will outline the currently held positions with regard to each one of these topics and why further research is warranted.

Effect of Fatigue on Performance and Learning

Alderman (1965) investigated the effect fatigue has on the performance and learning of the pursuit rotor and rho tests. Fatigue was induced by cranking an arm ergometer for ten minutes at a cadence of 120 rpm and with a resistance of 3.25 kg. The fatigue bout occurred once, between trials four and five on the rho test, which presented the subject with the task of making "a guided horizontal arm movement of a single orbit that blended into a target. The path of the movement is in the form of the lower Greek letter rho reflected and inverted" (p. 132). Fatigue also occurred once on the pursuit rotor test, between trials twenty and twenty-one. The fatigue bout was quite severe with the author reporting that "each subject became so fatigued he could no longer maintain the normal cadence" (p. 132). It was reported that the fatigue immediately caused a decrease in performance; however, the learning of the respective tasks was not affected. Alderman (1965) reported that the fatigue was administered at a point where approximately one-half of the learning of the tasks had occurred. It appears, however, that there was ample time following the fatigue bout for recovery and subsequent learning, which could explain the absence of the fatigue effect on learning.

Benson (1968) studied the effect of fatigue on the performance of two gross-motor tasks; a jumping task that involved going through a series of hopping and stepping movements, and a juggling task that involved alternate tossing and catching movements, using both hands. Fatigue was induced by riding a bicycle ergometer until the subject developed a heart rate of 180 beats per minute. Results showed the fatigue negatively influenced the performance of the jumping task. In both the Alderman (1965) study and the Benson (1968) study, muscles that were fatigued and then directly involved in the performance of the task showed a decrease in the performance. However, Benson (1968) also reported a "warm-up" effect with respect to juggling and jumping accuracy. Jumping accuracy results showed a plateauing of the control group learning curve after the seventh day of practice, while the experimental group continued to show gains throughout the investigation. Improved learning scores were also found in the juggling task, with the experimental group showing a more rapid acquisition of juggling skill. The finding of a warm-up effect as well as negative influence due to fatigue may be suggesting the existence of an inverted-U relationship. Further studies by Carron (1969), Schmidt (1969), Godwin and Schmidt (1969) and Carron and Ferchuck (1971) all found that fatigue, regardless of where it occurred in the practise session, always affected the performance of the task immediately following the fatigue bout. None of these researchers found the warm-up effect reported by Benson (1968), but rather all concur with the Alderman (1965) findings. A similarity between Alderman (1965) and the four mentioned studies was the fatiguing of muscles used in the task. It appears the fatigue was severe enough to affect performance, but the results do not preclude the possibility that a milder form of fatigue could create a warm-up effect resulting in improved performance.

While most literature seems in agreement that fatigue will cause a decrease in performance, a study by Cochran (1975) found differing results. Subjects were required to ride a bicycle ergometer for eight minutes and then perform a three minute practise trial on the stabilometer. This was followed by a further three minute ride on the bicycle ergometer, and a second three minute practise trial on the stabilometer. This treatment session was performed once per week for a period of four weeks. Results of the study showed the experimental group to have performed significantly better than the control group. The finding of a warm-up effect was in keeping with the Benson (1968) findings. Another interesting similarity in the two studies was their use of a distributed practise schedule. Studies that have found fatigue to impair performance have predominantly used a massed practise schedule, with a large number of practise trials being held over a period of one or two days.

Another significant difference between the Cochran (1975) study and other investigations is the different intensity and timing of fatigue. This difference in fatigue intensity may account for some of the difference in findings. Carron and Ferchuck (1971) and Cochran (1975) used very similar procedures. Both studies fatigued their subjects on a bicycle ergometer and then used a stabilometer as the motor task. However, in the Carron and Ferchuck (1971) study the subjects were re-fatigued after a twenty-second stabilometer trial while Cochran (1975) re-fatigued after a three minute stabilometer trial. Carron and Ferchuck (1971) have reported that the fatigue effects on a stabilometer task wear off very quickly because of the physically non-demanding nature of the task. It appears that any negative effect of the fatigue that may have been present in the Cochran (1975) study wore off, and the residual fatigue left a warming up effect, enhancing performance.

With respect to learning, Carron (1969) suggested that the stage at which the fatigue is introduced into the practice session is a critical factor. As in the Alderman (1965) study, Carron (1969) interpolated fatigue after certain percentages of the learning had occurred. In the Carron (1969) study fatigue was introduced after twenty-five and seventy-five percent of learning had taken place. Results showed that fatigue had no effect on learning.

Certain similarities exist between the Alderman (1965) study and the Carron (1969) study that may account for the agreement in the findings. Both studies used a massed practise schedule, both studies used a pursuit-rotor test, and both studies used a hand ergometer to induce the fatigue. The Benson (1968) study found fatigue to help learning by inducing fatigue prior to learning and using a more gross motor task. The differences between these studies may be suggesting a relationship between fatigue and the type of motor task as well as the type of fatigue condition.

One other explanation offered by Carron (1969) as to why learning was not affected was the possibility that the subjects recovered quickly from the fatigue and as a result practised in a non fatigued state long enough as to not affect learning. This possibility was a major concern of Schmidt (1969). According to Schmidt (1969) by giving only one bout of fatigue, the "fatigue could have been exerting a substantial effect while operating, but the large number of unfatigued trials may have allowed the subjects to recover and catch up" (p. 186).

In a precaution against recovery, Schmidt (1969) interpolated fatigue bouts between each pair of practise trials. Results of the study showed the fatigue not to alter learning significantly. This finding may be explained by the nature of the fatigue task. Analysis of the data indicated the fatigue effects did not appear to be significant until after trial four on day one. The learning curve of the control group showed that over one-half of the learning took place before trial four. It appears that the experimental group learned one-half of the skill before the fatigue had any influence. Previous studies that have purposely imposed fatigue when a certain percentage of the learning had taken place have also found that learning was not affected. It appears that for fatigue to have any effect it may have to be introduced before any learning has occurred.

A study by Godwin and Schmidt (1971), critical of earlier studies because of their tendency to allow subjects to recover, fatigued sixty-four subjects by rotating a handergometer similar to previous studies done by Alderman (1965) and Carron (1969). The experimental subjects rotated the handergometer for two minutes prior to trial one and for fifteen seconds between each task. The motor task chosen was similar to the rho task used by previous authors. The task used in this experiment was called a sigma task because of the sigma like motion it required. Godwin and Schmidt (1971) reported that none of the subjects were able to complete the one hundred and twenty revolutions of the wheel prior to task one. The authors felt that this inability to complete the task ensured an optimal level of fatigue. Findings indicated that the learning of this task was negatively affected. The authors reported that while the differences between the control and experimental groups were small, the difference was significant.

Carron and Ferchuck (1971) had subjects pedal a bicycle ergometer for 10 minutes before their first trial on a stabilometer, and then return to the bicycle for a two minute ride between trials. They found fatigue to adversely affect learning. However, there was concern expressed regarding the amount of impairment in the experimental group. The final six trials of the study, performed without fatigue, showed a rapidly diminishing difference between the control and experimental group. It was felt that because the stabilometer task required minimal amounts of movement and exertion, the experimental group was not put at a great disadvantage. As a result, the effect of the fatigue was possibly obscured.

A subsequent study by Carron (1972) was conducted using the Bachman Ladder Climb because this task required more physical exertion. Fatigue was induced identically to the previous study, with the subjects returning to the bicycle ergometer between practise trials. Results of the study showed learning to be negatively affected, with the difference lasting after two days of unfatigued practise. These findings may be suggesting that the more physically demanding the task, the greater the influence of fatigue upon learning.

While the findings of Godwin and Schmidt (1971), Carron and Ferchuck (1971) and Carron (1972) have all indicated that severe fatigue that is induced early and throughout the practise trials will negatively affect learning, their findings were not supported by later studies of Cotten, Spieth, Thomas & Biasiotto (1974) and Cochran (1975).

The study by Cotten et al. (1974) involved fatiguing a group of college students in either a local or a general fatiguing exercise. The subjects were then required to perform a modification of the Mirror Target Toss Test. The test involved ricocheting a volleyball off a hard surfaced wall onto a floor target while the subjects viewed the image of the target in a series of mirrors. The localized fatiguing condition consisted of reverse curling a twenty-three pound bar at a rate of thirty replications per minute for five minutes, while the general fatigue condition consisted of thirty ascents of a stool per minute for seven minutes. The authors reported that few individuals were able to keep up the pace for the required time. The subjects were re-fatigued after every second trial, meaning after ten attempts, performing their fatigue exercise for thirty seconds. Results indicated that neither the local or the general fatiguing conditions had any affect on learning.

A comparison of the Cotten et al. (1974) study with previous studies, indicate some procedural differences which may account for the conflicting findings. In the Godwin and Schmidt (1971) study the subjects were re-fatigued after each learning task. Examination of the data showed that the learning task took no more than 26 seconds to complete before the subjects were involved in another fifteen seconds of fatiguing exercise. In the Carron & Ferchuck (1971) study the subjects were refatigued after a twenty second trial. The Carron (1972) study also had a refatiguing situation after a twenty second practise trial. While the Cotten et al. (1974) study does not refer to the length of time required to complete the task, it may be assumed that to throw ten volleyballs accurately at a target while looking at mirrors will take substantially longer than twenty seconds. Perhaps the fatigue would be interfering with learning after one or two throws, but the effect may be non-existent after ten throws. As well, a thirty second re-fatigue trial may not be sufficient to re-introduce severe enough fatigue. The important criteria outlined by those authors that have found fatigue to influence learning is that fatigue must be severe. There is some question as to whether the fatigue in the Cotton et al. (1974) study could be classified as severe throughout the entire ten trials.

While most previous studies have used a massed practise schedule Cochran (1975) adopted a distributed practise schedule, similar to the structure of the Benson (1968) study. The Cochran (1975) study ran for a period of four weeks, with two trials given on the same day each week. Results of the study showed the experimental group to have learned the skill significantly better than the control group; in effect a warm-up similar to the Benson (1968) findings.

A comparison of the Cochran (1975) study with previous tests using the stabilometer may reveal an interesting relationship between fatigue and learning. Carron and Ferchuck (1971) reported a decrease in learning using the same apparatus as Cochran (1975). However, examination of the procedures may account for the difference. Cochran (1975) fatigued the subjects for ten minutes followed by a twenty second practise trial. It is evident that Carron and Ferchuck's (1971) subjects were kept in a higher state of fatigue. This factor alone may be accounting for the difference. The finding by Cochran (1975) of a warm-up effect may be offering further evidence of an inverted U model.

From the results of previous studies there appears to be a point where an increased activation level will enhance performance while further activation will result in a decrease in performance. More recent studies have dealt with the investigation of this possible phenomena. Gutin (1973) has suggested this relationship to be of a curvilinear nature and takes the shape of an inverted u. The inverted U model suggests that, as the level of activation increases, the performance level would improve up to an optimal point and then would deteriorate with further increases in activation.

In order to test this relationship accurately, it is necessary to examine more than two levels of fatigue. Pack, Cotten & Biasiotto (1974) used four levels of fatigue and examined what effect they would have on the Bachman Ladder Climb. Forty-eight college males were divided into one of four fatigue groups. These groups consisted of a control, heart rate 120 group, heart-rate 150 group, and heart-rate 180 group. To ensure that fatigue was maintained throughout the practise trials, each subject returned to the treadmill for sixty seconds between each ladder trial. All fatigue trials were held on one day with a retest under control conditions on day two.

An examination of the data showed that the performance of the severe fatigue groups, those individuals having heart rates of 150 and 180 beats per minute, decreased. These findings were in agreement with previous findings that severe fatigue would hinder performance. However, the results of this study do not reveal an inverted U relationship. In order to support the inverted U model, a warm-up effect should have been shown. The performance of the mild fatigue group should have been superior to the control group; however, this was not the case. Pack et al. (1974) claim that the reason the inverted U model did not reveal itself was "that both groups 150 and 180 fell on the right side of the continuum and groups 120 and control fell nearer the middle of the inverted U curve. Since considerable activation was involved in performing the ladder climb itself, the left side of the inverted U continuum may not have been adequately accounted for in the experimental design" (p. 195). The authors claim that their findings are in partial support of the inverted U theory. With respect to learning, severe fatigue was found to have a detrimental effect. However, as with the performance scores, the effect of fatigue on learning did not show an inverted U relationship.

In a further examination of the inverted U model Williams & Singer (1975) fatigued their subjects by using a bicycle ergometer modified to allow motor behavior similar to that with the hand ergometer, and then had the subjects perform a pursuit rotor task. The groups were divided into a light, moderate and severe fatigue conditions, representing heart-rates of 100-110, 135-145 and 165-175 beats per minute respectively. The mean performance scores for the four groups "assumed a crude approximation of the inverted U curve or even an inverted J curve" (p. 267). Learning data revealed the light fatiguing condition produced a warm-up effect, with the light fatigue group learning better than the control group. The severe fatigue group learned less than the control group indicating an inverted J model may be more representative of the relationship between fatigue and learning. While the differences between fatigue groups were not significant, there does appear to be support for the inverted model. However, questions remain as to the reliability of using heart-rate as a measure for a localized fatiguing condition. As well, the authors did not take pre fatigue scores, and given the relatively small sample in their study, this procedural oversight may account for the findings.

The inverted U model was expanded by Thomas, Doyice, Spieth & Abraham (1975) into an inverted J model. Thomas et al. (1975) claimed that "it seems foolish to suggest that severe levels of fatigue (activation) during performance will have the same effect as rest (opposite side of the inverted U). In fact, what may be more likely is fatigue has an effect similar to an inverted J rather than an inverted U" (p. 203). From the results of the study it is difficult to conclude that there does exist an inverted J relationship, as only two levels were used, a control group and an experimental group, with a heart-rate of 180 beats per minute. Thomas et al. (1975) did show that the severe fatigue group did perform at a lower level than the control group. However, they are only assuming the path of the performance curve took on an inverted J model. In order to display a curvilinear relationship it is necessary to use three or more fatigue levels.

In summary, it becomes evident from the literature on fatigue and performance that a severe level of fatigue will impair performance, regardless of where it is interpolated into the practise period. While the majority of studies showing fatigue to affect performance have used a massed practise schedule, the Benson (1968) study used a distributed practise schedule, but also showed a decrease in performance of a task using the muscles that were fatigued. It does not appear to matter what type of practise schedule is used, but rather to ensure the muscles performing the task receive a sufficient intensity of fatigue. A study by Cotten, Spieth, Thomas & Biasiotto (1974) compared local fatigue versus general fatigue on a motor task. Results indicated that both types of fatigue did impair performance, with the local fatigue perhaps being a little more harmful. Benson (1968) showed that an exercise that fatigued the lower limbs resulted in an improvement in a task requiring the use of the upper limbs. All other studies have attempted to fatigue the muscles doing the task, i.e., a local fatigue. The critical issue appears to be the severity of the fatigue in the functioning muscle. Gutin (1973) has suggested that differing severities will result in differing effects, and that a relationship will exist that can be described as an inverted U. This relationship indicates that mild fatigue will improve performance whereby at an optimal point fatigue will begin to impair performance. Two studies, Benson (1968) and Cochran (1975) have shown an improved performance because of the warm-up effect. While both of these studies lend practical support to the inverted U model, they were not designed to test that hypothesis. Studies that have attempted to clearly illustrate the relationship have been unsuccessful. Yet all these studies have found evidence for parts of the inverted U model. In one study that did show an inverted U relationship (Williams & Singer, 1975), a procedural component may have accounted for the difference. The proposed inverted J relationship by Thomas et al. (1975) may be the model that best describes the relationship. However, their study failed to show the curvilinear relationship.

In order to test the inverted U relationship it is necessary to use varying levels of fatigue and the fatigue levels must be dependent upon individual maximums. Researchers using a localized fatigue have monitored the fatigue levels by using heart-rate. However, the use of a central measure may be inappropriate with respect to localized fatigue. As well, group divisions have been based on an arbitrary external work measure. It is then assumed the physiological effects of the task are similar for each group. However, a moderate task for one individual may represent a medium task for another. A better procedure would be to have the subjects operating at a percentage of their own maximum, thus ensuring a similarity within groups. It is apparent that before accepting the inverted J model further study is warranted.

Studies that have found fatigue to have no effect upon learning have been criticized for not supplying a severe enough fatigue. Two studies, Benson (1968) and Cochran (1972) using a general type of fatigue found it to enhance performance. However, studies using a localized fatigue have for the most part failed to show any warm-up effect. The reason for this may be due more to the severity of fatigue rather than the local vs general fatigue. Benson (1968) also found the general fatigue to affect learning when the muscles used in the learning were the ones fatigued.

The issue of a massed versus a distributed practise schedule appears to be irrelevant. Benson (1968) and Cochran (1975) both used a distributed practise schedule, with differing results. Again the issue appears to be the intensity of the fatigue.

It appears that for fatigue to be a factor it must be of a severe nature and be introduced early in the practise schedule. Schmidt (1969) interpolated severe fatigue into the practise trials at a point when the learning was over half completed, and found the fatigue to have no effect.

Carron and Ferchuck (1971) and Carron (1972) have shown that fatigue may affect motor tasks differently. They found different learning effects when using the stabilometer versus the Bachman Ladder Climb. However, it may be that the issue is not differing skills but rather the fatigue is relative to the tasks. Again perhaps the severity of the fatigue is the critical issue.

For the purpose of this paper the inverted U relationship is the main concern. Can the inverted U model be used to describe the relationship between fatigue and learning? Studies to date have failed to clearly illustrate this relationship. It is therefore necessary to continue with further research, using a variety of fatigue levels in order to test this model further.

The Effect of Fatigue on Reaction Time

Central and Peripheral Fatigue

One of the purposes of studying fatigue and its effect upon reaction time is to offer a possible explanation for the physiological location of fatigue. While it is beyond the scope of this paper to investigate fully the topic of fatigue, some understanding of the two current theories is valuable in interpreting current reaction time research.

Kroll (1973) stated that "fatigue associated with skeletal muscles, has been differentiated from a kind of 'mental' fatigue associated with the central nervous system actions" (p. 81). The two types of fatigue Kroll (1973) refers to are more commonly referred to as central and peripheral fatigue. Asmussen (1979) offers a good summary of the characteristics of both types. According to Asmussen (1979) there are actually "two separate regions fatigue can set in: a peripheral region distal to the stimulated motor nerves and a central region proximal to this place" (p.

315). In peripheral muscle fatigue there are again at least two different sites. Firstly, the transmission mechanism which consists of the neuromuscular junction, muscle membrane, and endoplasmic reticulum; and secondly the contractile mechanism, consisting of the muscle filaments. Asmussen (1979) claims that peripheral muscle fatigue occurs because of local changes in the internal structure of the muscle. These changes may be "biochemical consisting in the depletion of substrates such as glycogen, high energy phosphate compounds, acetylcholine, or an accumulation of metabolites" (p. 316).

Central fatigue appears to be caused by an inhibition "elicited by nervous impulses from the receptors in the fatigued muscles. The inhibition may act on the motor pathways anywhere from the voluntary centres in the basin to the spinal motor neurons" (Asmussen, 1979, p. 320). Fatigue of this type would manifest itself by a decrease in the outflow of motor impulses to the muscles.

In light of the questions regarding fatigue and reaction time, Kroll's (1974) statement appears to summarize best the direction current research has taken. "By combining research techniques for assessment of muscular fatigue with motor learning protocol for studying fatigue effects upon reaction time, a more adequate understanding of reaction time and fatigue effects may be possible" (p. 83).

Reaction Time Studies

Similar to research dealing with performance and learning, the fatigue and reaction time studies reveal inconsistent and conflicting results. Levitt and Gutin (1971) and Bender and McGlynn (1976) have shown fatigue to create a physiological warm-up, improving reaction time. Both studies suggest the inverted U relationship, proposing an improvement (decrease) in reaction time under mild fatigue conditions with a subsequent increase in reaction time in response to severe fatigue levels. The inverted U relationship has been alluded to with respect to performance and learning studies, and these findings may indicate a relationship between fatigue effects in reaction time and fatigue effects on performance and learning.

While the studies by the previous authors investigated reaction time in an unfractionated state, the majority of reaction time studies have dealt with fractionated reaction time. Fractionated reaction time methodology was developd by Weiss (1965) and involved dividing reaction time into two components; pre-motor time and motor time. Using surface EMG measurements, Weiss (1965) measured the time interval between the onset of a stimulus, and the appearance of muscle action potential, termed pre-motor time. The motor time component represented the time interval from the muscle action potential until actual limb displacement. Total reaction time was then expressed as the sum of the motor time and pre-motor time components.

Studies by Kroll (1973, 1974), Hayes (1975) and Kamen, Kroll, Clarkson, and Zigon (1981), using the fractionated technique, fatigued subjects to levels representing between twelve and thirty-four percent of maximum. Results of these studies showed fatigue to have no effect upon reaction time. It appears the fatigue level was too small to induce any changes, either positively or negatively. No warm-up effect as reported by previous authors appeared.

Reflex time was also measured by Kroll (1974) and Hayes (1975) and was found to be affected by the fatigue condition. As a result of the disturbances within the reflex time component, both authors concluded that the locus of the fatigue was peripheral, located in the contractile elements of the muscle.

Klimovitch (1977) increased the fatigue level to a 42% strength decrement for one group and a 55% strength decrement for another. Both fatigue groups demonstrated an increase in motor time and reaction time. Klimovitch (1977) reported a 19 msec. increase in motor time in the 42% fatigue group and a 33 msec. increase in the 55% fatigue group. A study by Stull and Kearney (1978) fatigued twenty male subjects to levels representing 20, 40 and 60% strength decrement. The authors reported that motor time showed a linear increase in time with a marked increase at the 60% level. At the 60% level, motor time was increased by approximately 29% when compared with the value obtained at a non fatigued state. This change in motor time is consistent with the finding of Klimovitch (1977) who found motor time increased 28% following a 42% decrement and 38% following a 55% decrement. The findings of Klimovitch (1977) and Stull and Kearney (1978) do not agree with the findings of previous authors. However, the apparent differences in fatigue levels probably accounts for this difference. The apparent need for a sufficient fatigue level before any fatigue effects upon reaction time can be observed, may be suggesting a threshold level with respect to fatigue and reaction time.

Morris (1979) tested the reaction time of knee extension under two conditions, either a resisted or unresisted state. Fatigue was induced by either an isometric exercise resulting in a 36.6 percent decrement or an isometric task creating about a 57 percent strength decrement. Reaction time for unresisted reaction time had no change while an increase in motor time was responsible for the increased reaction time in the resisted condition.

Morris (1977) offers two possible explanations as to why the motor time in the resisted reaction time increased. Firstly, it was suggested that the additional resistance, together with the strength decrement, was too great for the central nervous system compensating process to assert itself and therefore a lengthening of motor time resulted. It appears that the addition of the extra resistance reduced the number of extra motor units that could be called upon to relieve fatigued muscles, and as a result the fatigue manifested itself in the prolonged reaction time.

A second possible explanation has to do with cortical firing patterns associated with different force levels. "In other studies in which cortical activity was monitored during forceful planned movements it was found that electroencephalographic activity was altered due to these different movements" (Morris, 1977, p. 9). Wood (1977) suggests there may exist two or more motor systems for voluntary control of movement. One system to deal with velocity and a second system for the different force demands.

Wood (1979) also investigated the effect of fatigue upon resisted reaction time, however, he also subdivided the pre-motor component. These subcomponents consisted of a measure of visual reception time, opto-motor integration, time and motor outflow time. Wood (1979) defined these components as follows: reception time (RCT) is the "time delay between presentation of visual stimulus and the first appearance of a visually evoked cortical activity as evidenced by the primary component of the averaged visual evoked potential" (p. 249). The motor outflow time (MOT) was defined as the "time delay between cortical activity associated with cortico-spinal outflow, evidenced by the onset of the dominant negative component of the averaged motor potential and the beginning of electromyographic activity in the responding musculature" (p. 249), as measured by surface electrodes. Opto-motor integration time (OMIT) is the "time delay between cortical reception of visual stimuli and cortico-spinal discharge, i.e., from the end of RCT to the beginning of MOT" (p. 249).

Two fatigue intensities were used, resulting in a 42 percent strength decrement and a 33 percent strength reduction. The author reported a significant increase for total reaction time and its two major components: pre-motor and motor time. A change in motor outflow time was also reported, but was not significant. It was concluded that the fatigue effects were primarily peripheral, "as evidenced by a decrease in maximum voluntary contractile force and a diminished rate of tension development" (p. 255). However, because of the increase in pre-motor time, there is some suggestion of a disturbance in central processing.

Two studies, Hanson and Lofthus (1978), and Lofthus and Hanson (1980) expanded the issue of fatigue and reaction time by adding a variable of left-right dominance. Swimmers (bilateral athletes) and tennis players (unilateral athletes) were used in the study. Fatigue resulted in a 50 percent decrement in hand grip strength. Results of the study showed the reaction time to increase, due to an increase in pre-motor time. The increased pre-motor time with the relatively stable motor time is in marked contrast to the results of Klimovitch (1977) and Stull and Kearney (1978). The differences in reaction time components between dominant and nondominant limbs were not significant. The conflict between these studies and previous studies, according to the authors, may be due to the characteristics of the subjects and may "lend further evidence to support the implication of muscular fiber type composition as a contributory factor in efficient sensorimotor task performance" (Hanson & Lofthus, 1978, p. 182). This study may suggest a difference in fatigue effects between dominant and non dominant arms, indicating a procedural concern in fatigue studies.

In a follow-up study, Lofthus and Hanson (1980) expanded to a bilateral simultaneous hand grip task in contrast to the single limb hand-grip task used in their initial study. Results showed for the preferred limb no significant increase in reaction time. Significant differences were found for pre-motor time, however the improvement in motor time maintained overall reaction time. Exercise effects on the non-preferred arm resulted in an increase in total reaction time, caused by an increase in pre-motor time, while motor time remained unchanged. The over-all superiority of the preferred limb performance was significant.

Possible subject differences were studied by Kamen et al. (1981). Power trained and endurance trained athletes participated in the study which showed no increase in total reaction time. Some differences were observed between the two groups. One of the major flaws of this study, in the opinion of this author, was the choice of fatigue levels. Previous studies, using non-athletes for subjects, have already reported no fatigue effects using similar fatigue levels.

In summary, it appears that fatigue will effect reaction time, providing the fatigue level is of sufficient intensity. It appears that the effect of the fatigue is generally peripheral, however later studies have revealed a change in pre-motor time, suggesting fatigue of the central nervous system. Because of the suggested influence of subject variability, type of task, and varying fatigue levels on reaction time, it is not possible at this time to draw any direct relationship between reaction time and performance and learning. For the detection of any existing relationshp it would be necessary to test fatigue and its effect upon performance and learning and simultaneously how reaction time fluctuates under fatigue conditions.

CHAPTER 3

METHODS AND PROCEDURES

The purpose of this study was to investigate whether there is a relationship between reaction speed and performance/learning measurements under fatiguing conditions, and whether fatigue effects performance and learning.

In this chapter, the methods used for selecting the subjects, as well as the type of subjects will be discussed. As well, the methods for the research, data collection, and the hypothesis will be discussed.

Subjects

Thirty-five right-handed male volunteers enrolled in first or second year Physical Education and Recreation Studies at the University of Manitoba participated in the study. They were randomly assigned to one of five groups; a control or one of four experimental groups. Assignment to experimental group occurred prior to the pre-testing day.

Experimental Design

1. Pre-Testing. The purpose of the pre-test was to ascertain the amount of resistance on a bicycle ergometer, modified to permit craking by hand in the upright position, that would result in the individual being unable to continue cranking at two minutes, plus or minus ten seconds. The procedure for the pre-testing was as follows.

1. The subjects reported to the testing situation where they were required to arm crank a bicycle ergometer at 50 rpm, first with the left arm and then with the right. The resistance was set by the experimenter. The resistance that resulted in the subject's inability to continue cranking at two minutes plus or minus ten seconds, while using the right hand, was referred to as the individual's maximum.
2. Individuals assigned to the 25% fatigue group were exercised during the testing day at 25% of their maximum. The 40% group exercised at 40% maximum, the 60% group exercised at 60% maximum, and the 80% group exercised at 80% maximum. The control group exercised at a zero tension.

2. Testing. All subjects were fitted with three surface electrodes over the triceps muscle to record tricep activity during the reaction time trials. Once the electrodes were

attached, subjects were seated on a stool that permitted access to the bicycle ergometer, pursuit rotor, and reaction time by simply turning the stool. Subjects then performed a reaction time test followed by a pursuit rotor test. The alternating of tests continued until three reaction times and three pursuit-rotor tests were completed. The three tests represented the pre-learning scores.

Following the three pre-learning trials, all subjects performed two minutes of hand cranking the bicycle ergometer at their respective work levels. Refer to work levels Table 11, Appendix A. Immediately following the two minute exercise period, the subjects performed one reaction time trial followed by one twenty-second pursuit-rotor test. Upon completion of the pursuit-rotor test, the subject then returned to the bicycle ergometer for a further fifteen seconds of exercise, followed by the reaction time and pursuit rotor tests. This procedure was continued until twenty-three trials, including the three pre-test trials were completed. In an attempt to increase the validity of the testing, subjects were requested not to engage in any strenuous activity prior to the testing.

3. Post-Test. During the post-test all subjects performed five pursuit-rotor trials under non-fatigue conditions. The post-test occurred forty-eight hours after the testing day, at as close to the same time of day as the testing situation. Refer to Figure 1 for an illustration of the study design.

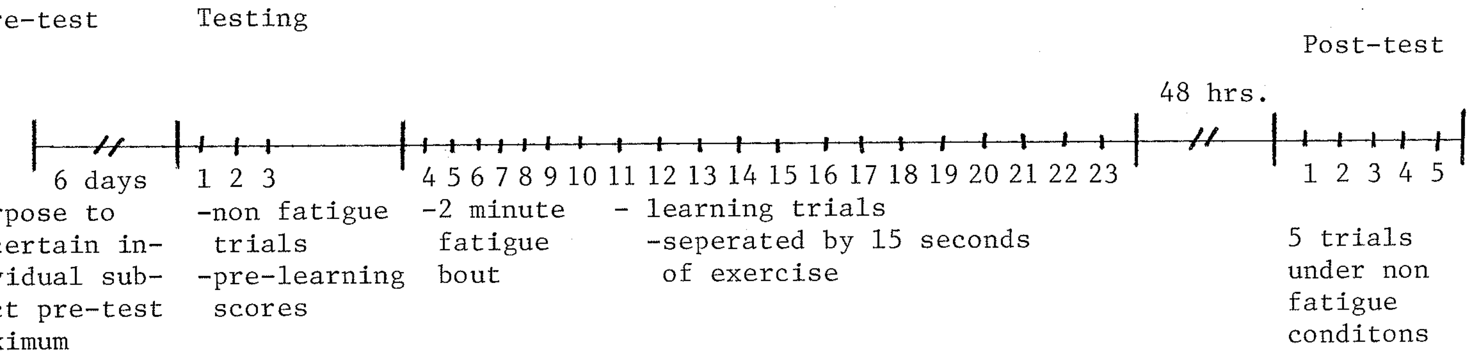

Figure 1: Chronological Representation of Study Design

Data Collection

Apparatus

1. Pursuit Rotor:. A Lafayette Pursuit rotor model #30013 was used as the motor task. Subjects performed the task by holding a light sensitive stylus with their right hand. The pursuit rotor was set in a vertical position at shoulder joint height and was set at fifty revolutions per minute. An automatic timer recorded the time on target for each trial. A second timer was used to time the length of each twenty second trial.

2. Bicycle Ergometer:. A standard Monark Bicycle Ergometer was used, with one pedal removed and replaced by a hand grip, similar in size to the pursuit-rotor stylus. The bicycle was set up on a table in a vertical position, so that the axis of the pedal was at the level of the subjects

shoulder joint. The subject rotated the pedal at fifty rpm at the required resistance for two minutes and then for fifteen seconds between each performance trial.

3. Reaction Time:. A special device was designed to test reaction time (Appendix C). Two switches were mounted on a board seperated by a semi-circle of styrofoam. The diameter of the styrofoam was the same as the pursuit-rotor and the diameter of the pedal rotation. The device was then mounted on a table that resulted in the two switches being at the same height as the centre of the pursuit-rotor circle and the axis of the bicycle pedals. The subjects grasped a stylus as if grasping a pencil and then supressed a switch mounted on the right side of the board. Upon hearing an auditory stimuli the subject released the switch, and moved in a downward clock-wise direction, following the semi-circular pattern formed by the styrofoam, to the other switch. By using surface electrodes attached to the triceps muscle, the reaction time was seperated into pre-motor and motor components. The reaction time components were measured by an electrocardiograph, Model VS-4, specially attached to the reaction time device.

Data Analysis

The following statistical procedures were used in the analysis of the data:

1. 5 (groups) x 28 (trials) Anova with repeated measures Pursuit Rotor Scores.
2. 5 (groups) x 6 (trial blocks) Anova with repeated measures Pursuit Rotor Scores.
3. Correlation between reaction time and pursuit-rotor scores.
4. An Anova on learning scores as defind in Chapter 1.

In the above statistical analyses, null hypotheses of no differences or no correlation were tested at the .05 and .01 levels of confidence.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine the effect of fatigue on the performance and learning of the pursuit-rotor. Thirty-five males enrolled in first and second year Physical Education and Recreation Studies at the University of Manitoba volunteered to act as subjects. The subjects were randomly assigned to either the control or one of four treatment groups. All subjects hand cranked a modified bicycle ergometer for two minutes at a predetermined resistance prior to testing, and for fifteen seconds between each subsequent trial. Trials 1-3 were performed without the fatigue condition. Trials 24-28, representing the post-experimental condition, were conducted forty-eight hours after the experimental trials and were performed without interpolated fatigue.

In this chapter, the results of the statistical analyses will be presented as well as relevant tables and graphs. A discussion of the findings will follow the presentation of the statistical analyses.

Results

Performance

Performance data were grouped into six trial blocks, expressed as mean 1 (average trials 01-03), mean 2 (average trials 04-08), mean 3 (average trials (09-13), mean 4 (average trials 14-18), mean 5 (average trials 19-23) and mean 6 (average trials 24-28). Table 1 presents the mean and standard deviation of the six trial blocks for each fatigue group. The mean and standard deviation for each trial are found in Table 10, Appendix A.

Mean performance scores for the control and four experimental groups are presented in Fig. 2. The graph displays a negatively accelerating curve, over mean trials. Performance improvement on the pursuit-rotor was most abrupt between mean 1 and mean 2, with smaller improvements throughout the remaining trials. A reminiscence effect is evident for all groups. Negative fatigue effects appear to be most pronounced on subjects within the 60% group while the 25% groups's performance appears to be facilitated through means 4 and 5. The remaining three groups appear to have quite similar performance scores throughout the trials, with a small difference appearing at mean 5.

The performance data were analyzed using a 5 (treatments) x 28 (trials) Analysis of Variance with repeated measures. Calculations of the ANOVA was performed using a Statistical

Table 1

Trial Blocks Means and Standard Deviation for Pursuit Rotor Performance Scores by Fatigue Group

	Control		25%		40%		60%		80%	
Trials	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Mean 1	4.123	.9072	4.182	.7403	4.727	1.599	4.305	1.380	4.148	1.172
Mean 2	6.079	.6391	6.125	1.815	6.456	1.570	5.713	1.789	5.828	.612
Mean 3	6.598	.8143	6.326	1.868	6.594	2.028	6.236	1.871	6.489	.501
Mean 4	7.006	.7584	7.440	1.208	7.167	2.409	6.098	1.228	7.036	.850
Mean 5	6.869	.9042	7.568	1.183	7.350	2.446	6.633	1.604	7.161	1.166
Mean 6	8.310	.7825	7.961	.978	8.713	2.022	7.716	1.153	7.953	.191

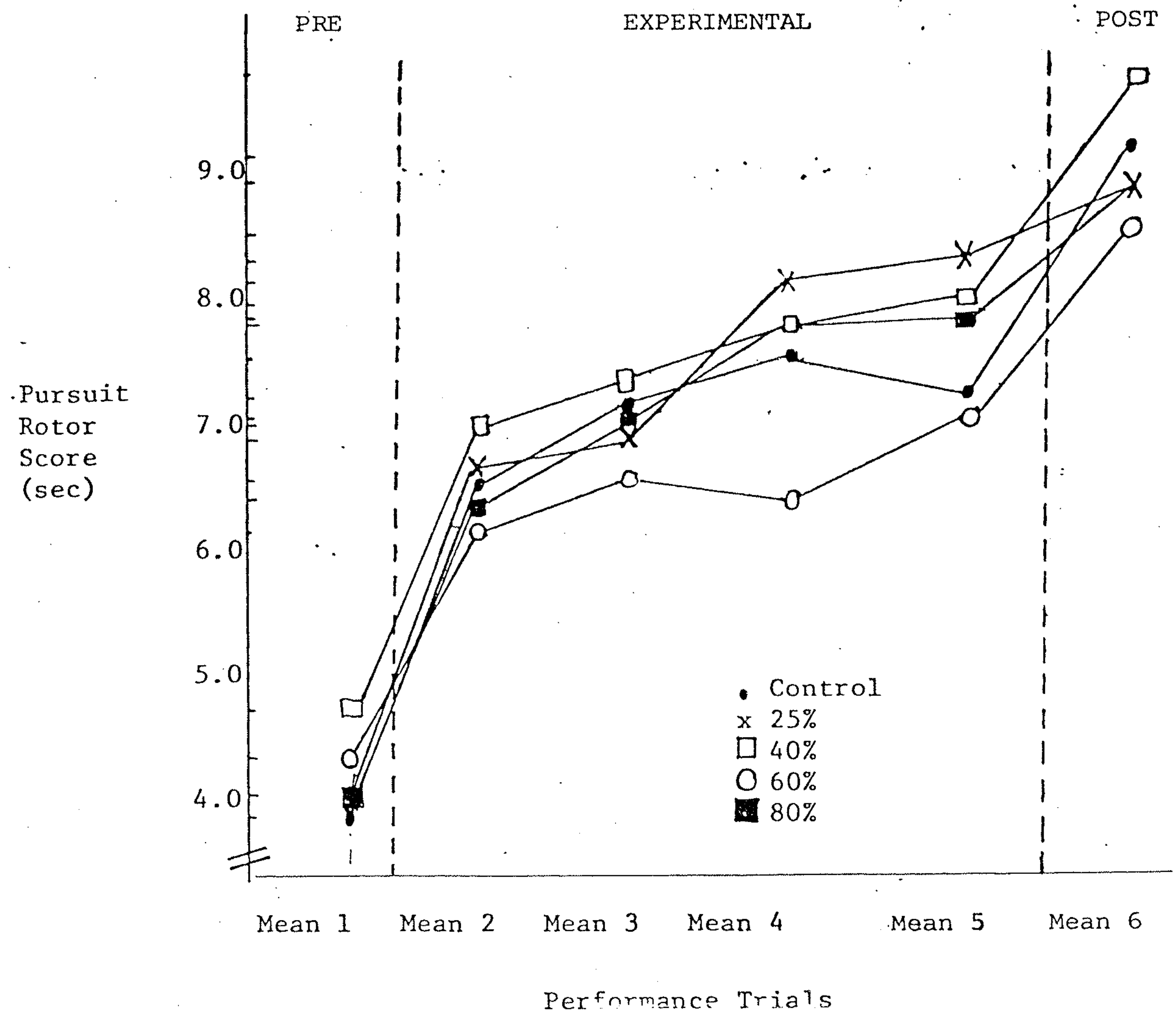

Figure 2. Mean Pursuit Rotor Performance Scores by Fatigue Group

Analysis (S.A.S.) computer program, General Linear Models Procedure. As presented in Table 2 the fatigue effect, indicating differences between levels of the fatigue treatment was not significant, $F(4,30)=.36$. The fatigue x trials interaction, measuring differences between groups at similar trials was also not significant, $F(108,810)=.98$.

The subject within fatigue effect was significant, $F(30,810)=28.94$ indicating a wide variability between subjects within the same fatigue group. The trials effect was also significant, $F(27,810)=33.70$ indicating improvement in performance scores over the twenty-eight trials.

The trial blocks Analysis of Variance (Table 3) revealed similar results as the previous analysis. The fatigue effect and fatigue x trials interaction were not significant $F(4,30)=.30$ and $F(20,150)=.60$ respectively. Significant differences for the subject within fatigue effect and the trials effect were found, $F(30,150)=11.52$ and F)5,150)=8.92 respectively.

Table 2

Summary Anova Table for Fatigue x Trials of Pursuit Rotor Performance

Source	Type 1 S.S.	DF	Mean Sq.	F value
Fatigue	57.4928	4	14.3732	.36
Subject (Fatigue)	1169.7582	30	38.9919	28.94*
Trial	1225.8961	27	45.4036	33.70*
Fatigue x Trial	142.2725	108	1.3173	.98
Error	1091.2985	810	1.3473	

*Significant at .0001 level

Table 3

Summary Anova Table for Fatigue x Trial Blocks of Pursuit Rotor Performance

Source	Type 1 S.S.	D.F.	Mean Sq.	F value
Fatigue	11.4804	4	2.8701	.35
Subject (Fatigue)	243.3504	30	8.1117	11.52*
Trial	288.4290	5	57.6858	81.92*
Fatigue x Trial	8.4759	20	.4238	.60
Error	105.6303	150	.7042	

* Significant at .0001 level

Regression Analysis

Due to the apparent wide variability existing between subjects within the same fatigue group, a regression analysis was conducted using the S.A.S. computer package. The regression analysis confirmed the existence of wide within group variability. The variability of response the fatigue condition made determining group trends difficult.

Examination of the regression graphs revealed a consistency in response within the control group. However, the regression lines within the fatigue groups display wide variability, with greatest variability within the 40% and 60% fatigue groups. Individual regression lines show some subjects displaying almost a horizontal regression, suggesting no improvement in performance over the twenty-eight trials. These horizontal lines were evident in the 25%, 40% and 60% fatigue groups. No horizontal regression lines were evident in the control or 80% fatigue group. Some individuals displayed a great deal of improvement, while others only small gains in performance.

Learning

A learning score for each subject was by subtracting mean 1 (average trials 01-01) from mean 6 (average of trials 24-28). Table 4 presents the mean learning score and standard deviation for each fatigue group. An Analysis of Variance was performed on the learning scores, using the S.A.S. computer package. A non-significant F value of $F(4,30)=.24$ was found. It appears from the lack of a significant difference between treatment groups that the fatiguing condition did not alter the learning of the pursuit-rotor. Table 5 presents a summary Anova Table for the learning scores.

A reminiscence effect can be observed for all fatigue groups, however a t-test indicated that the effect was only significant for the control group. Table 4 presents the mean, standard deviation and t values for the reminiscence.

Table 4

Means and Standard Deviations for

Learning and Reminiscence

	Learning		Reminiscence		
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	t
Control	4.083	.637	1.33	.485	7.30*
25%	3.778	1.131	.388	1.213	.85
40%	3.896	1.791	1.364	1.903	1.90
60%	3.411	1.879	1.08	2.023	1.42
80%	3.804	1.189	.791	1.183	1.77

*Significant at .001 level

Table 5

Summary Anova Table for Learning Scores

Source	Type 1 SS	D.F.	Mean Sq.	F. value
Fatigue	1,8595	4	.4649	.24
Error	59.03	30	1.9678	

Graphical Group Comparisons

Statistical analyses indicated that fatigue did not have a significant effect upon the performance of the pursuit rotor task. Graphical presentation of the data, (Fig. 3), comparing group scores at the same mean trials, may be interpreted as containing some support for an inverted u relationship. It can be observed from Fig. 3 that relative to the pre-test levels, the 25% group became more facilitated over trial blocks, whereas the 40% groups, which in early trial blocks appeared facilitated by the fatigue, showed a relative decrease in performance over later trial blocks. During the learning trial blocks, the 60% groups relative improvements were the lowest of all experimental groups, which may point to an inhibitory fatigue effect. The performance curve at mean 6 (post-test) resembles the configuration apparent during the pre-test condition. It may be surmised that the fatigue effects, which appeared to create the inverted U relationship in earlier trial blocks, have dissipated. The learning scores, presented in Fig. 4, did not reveal the appearance of an inverted U relationship. Rather, the relationship between fatigue groups assumes a curve similar in shape to the post-test condition.

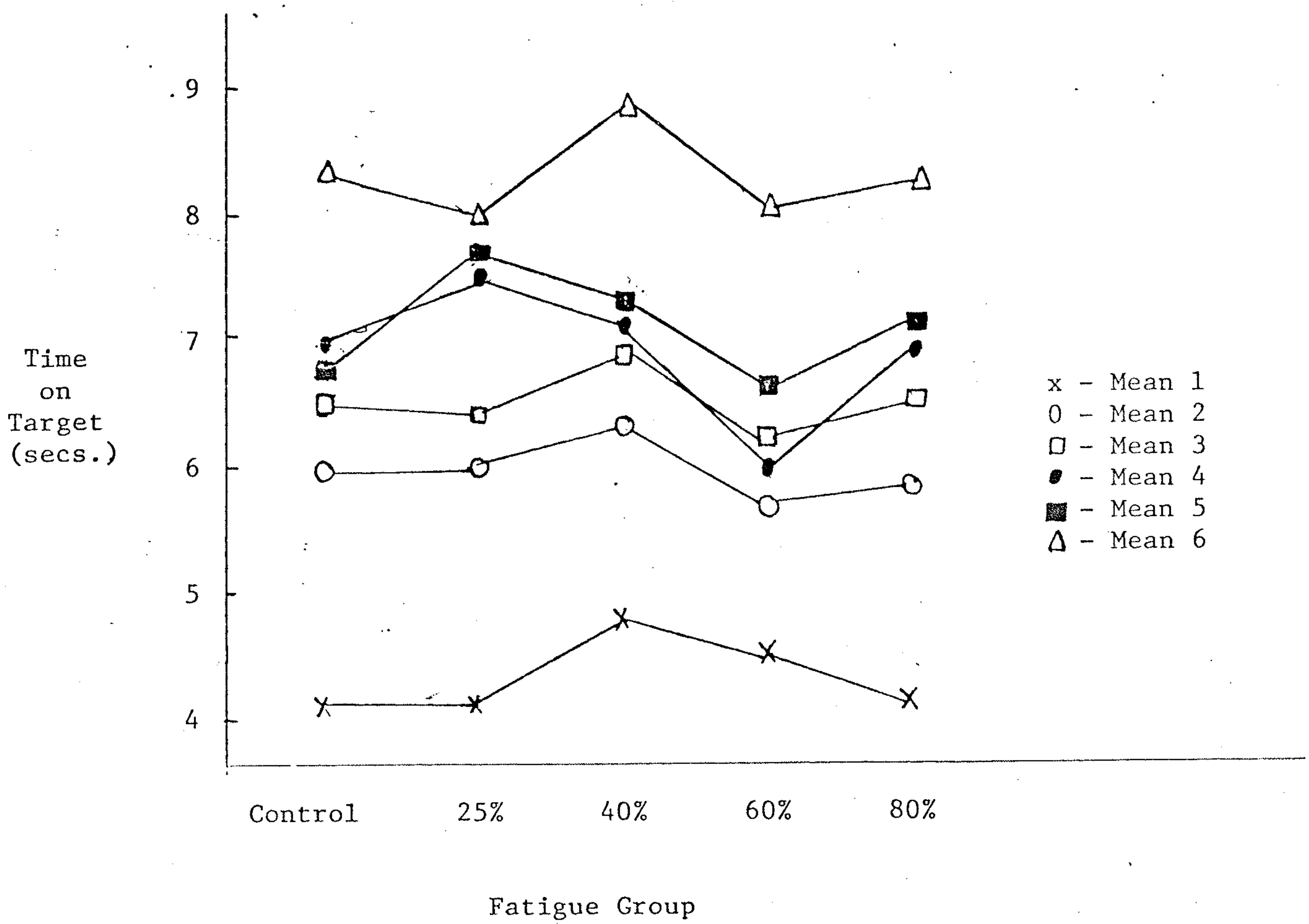

Figure 3. Mean Pursuit Rotor Scores

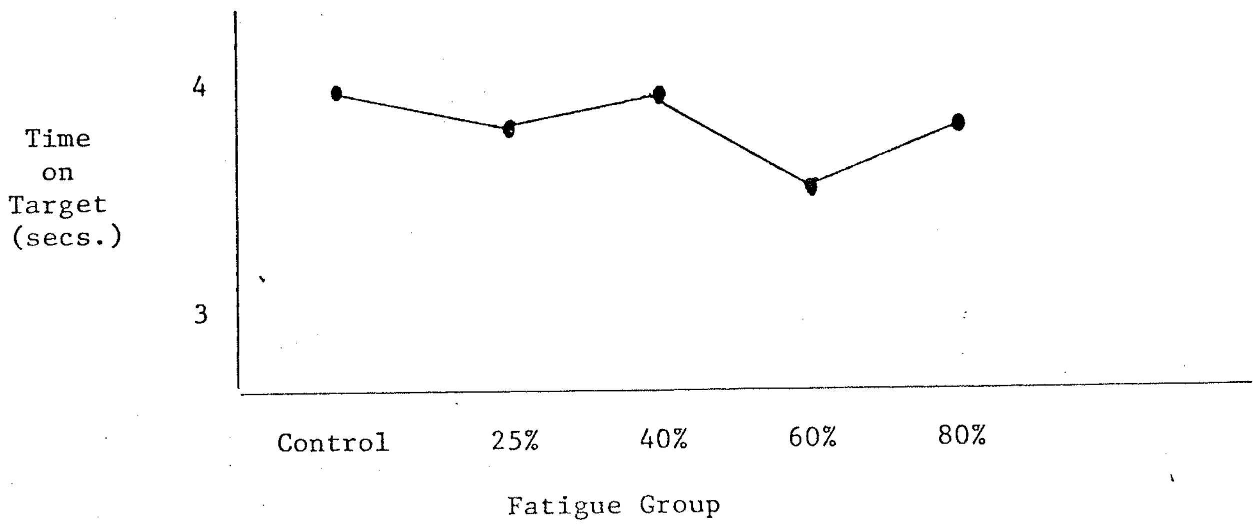

Figure 4. Mean Learning Scores

Reaction Time

Reaction Time data were grouped into five trial blocks, expressed as mean 1, mean 2, mean 3, mean 4 and mean 5. Table 6 presents the means and standard deviations for the five trial blocks for each fatigue group.

A comparison of group reaction time scores at the same mean trials is presented in Figure 5. There are no obvious trends apparent from the graph. While the moderate fatigue levels show an increase in reaction time scores through means 1-4, as compared to the control group, the 80% fatigue group displays much better reaction time scores through these same means when compared to all other groups. Mean 5 shows a reversal effect with the moderate fatigue levels showing a faster reaction time score as compared to the control group. The best reaction time scores were still displayed by the 80% fatigue group. Continued exposure to the fatigue condition appeared to enhance reaction time performance in the 40% and 60% fatigue group. The same time under fatigue conditions resulted in an increase in reaction time scores for the 80% fatigue group, however the reaction time recorded by these subjects were the fastest of all groups throughout the trials.

Reaction time was separated into its pre-motor and motor components. Means and standard deviations for the five trial blocks of pre-motor and motor time for each fatigue group are presented in Tables 7 and 8 respectively.

Graphical presentation of pre-motor and motor trial block means is illustrated in Figure 6. Correlations between reaction time, pre-motor time, motor time on the one hand and pursuit rotor scores on the other were calculated using a S.A.S. Computer Package. No clear correlation pattern between the respective variables was evident. Some correlations were positive, some negative, but all were relatively low. A complete presentation of the correlation coefficients can be found in Table 9.

Table 6

Trial Blocks' Means and Standard Deviation for Reaction Time Scores (msec)

	Control		25%		40%		60%		80%	
Trials	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Mean 1	218.56	53.163	238.70	37.20	232.00	46.39	245.14	3220	228.00	52.44
Mean 2	238.00	17.75	222.71	27.00	244.71	36.57	244.57	19.90	192.43	23.00
Mean 3	226.57	14.52	224.71	30.18	247.43	67.46	235.29	37.84	190.00	21.61
Mean 4	233.00	19.72	214.57	30.20	224.57	47.94	247.43	38.97	210.71	18.60
Mean 5	239.86	24.24	230.43	35.21	220.00	50.96	222.57	28.35	206.00	22.29

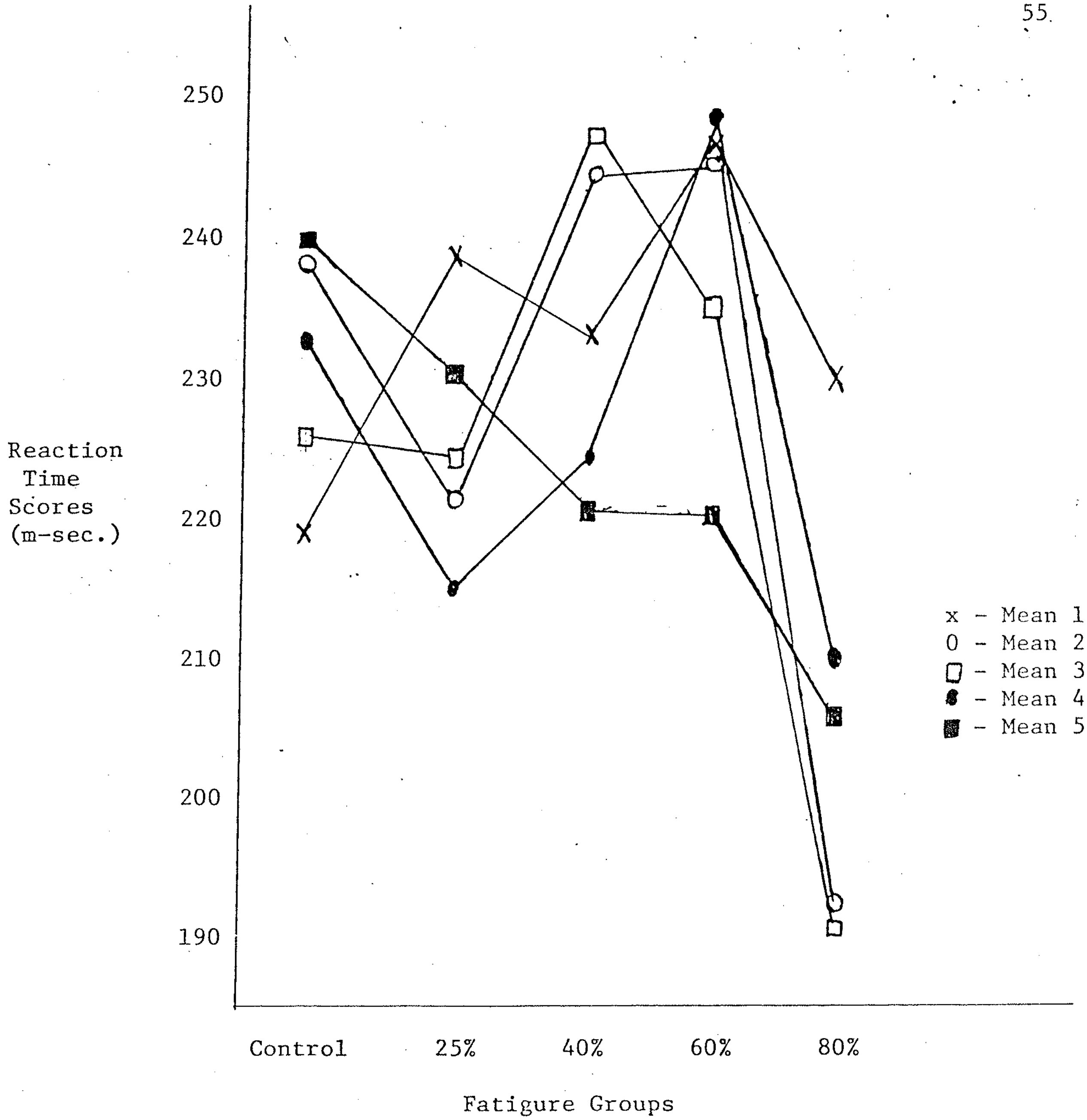

Figure 5. Mean Reaction Time Scores

Table 7

Trial Blocks' Means and Standard Deviation for Premotor Scores (msec).

	Control		25%		40%		60%		80%	
Trials	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Mean 1	157.14	41.43	158.11	25.28	179.57	37.0	169	31.15	168.51	49.03
Mean 2	171.14	20.38	149.0	20.69	169.57	38.46	168.57	23.90	129.71	29.70
Mean 3	159.28	22.81	148.28	29.31	175.0	57.99	164.85	41.46	119.57	18.71
Mean 4	188.71	71.29	158.71	56.88	152.14	40.98	173	35.36	130.0	25.77
Mean 5	170.42	26.67	152.14	37.64	143.71	40.79	145.57	22.57	126.14	20.34

Table 8

Trial Blocks' Means and Standard Deviation for Motor Scores (msec)

	Control		25%		40%		60%		80%	
Trials	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D
Mean 1	53.14	17.09	65.28	11.02	61.71	14.63	76.57	11.77	77.43	46.63
Mean 2	66.85	6.59	73.14	11.09	73.71	15.86	75.14	14.53	62.43	12.83
Mean 3	68.57	11.28	76.85	7.98	74.28	20.20	76.43	19.50	70.57	10.06
Mean 4	73.14	8.47	79.42	12.14	73.29	17.12	79.85	20.10	81.43	12.54
Mean 5	73.14	13.22	79.28	11.16	76.85	14.47	83.57	16.81	81.28	11.12

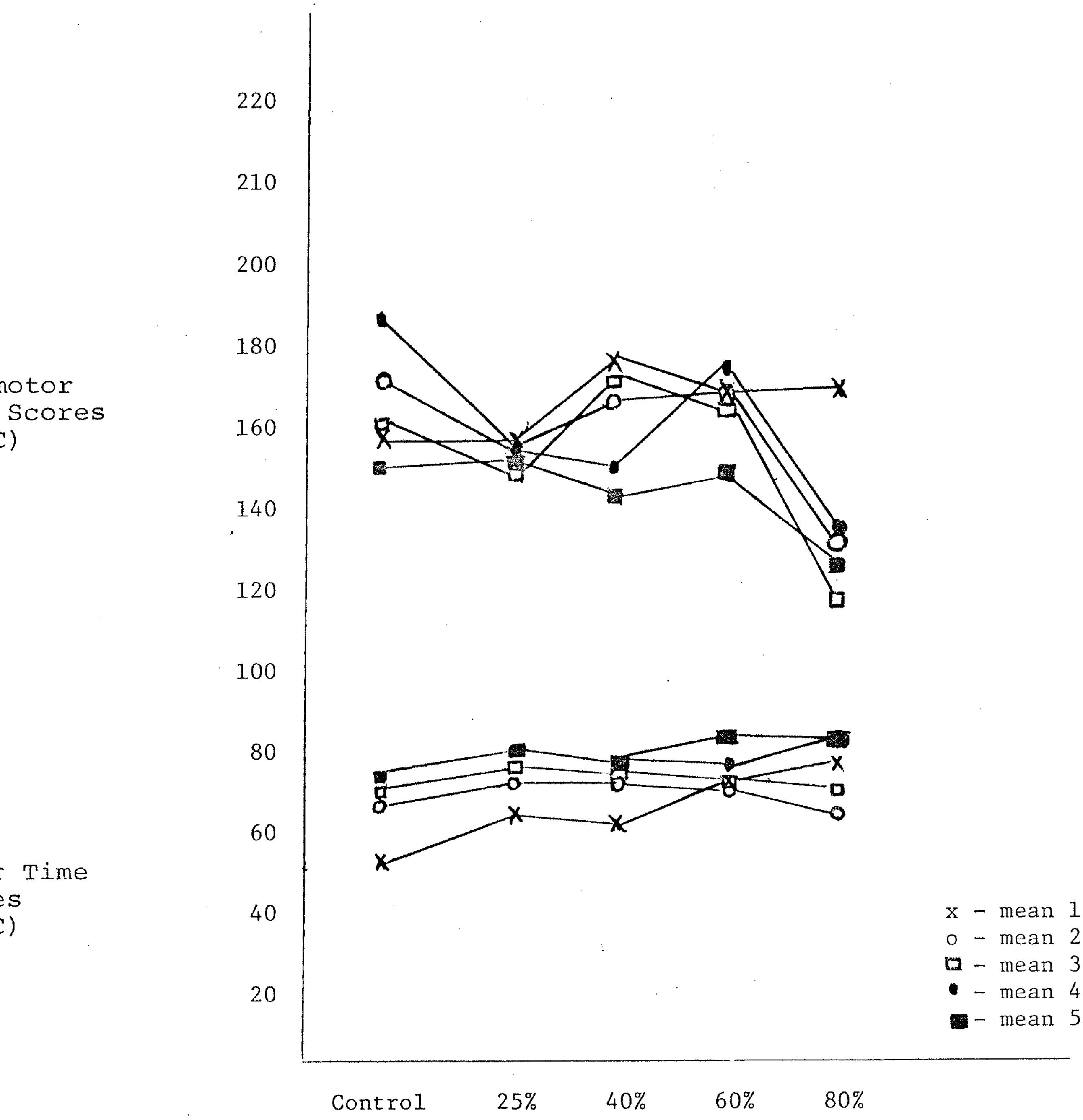

Figure 6. Mean Pre-motor and Motor Time Scores

Table 9

Correlation Coefficients for Reaction Time Components and Pursuit Rotor Scores

	Control	25%	40%	60%	80%
M.T.-P.M.	.08	-.46**	-.16*	.05	-.70**
M.T.-R.T.	.47**	-.19*	.12	.41**	-.62**
M.T.-P.R.	.64**	.22**	.20**	-.30**	.01
P.M.-R.T.	.92**	.96**	.96**	.93**	.99**
P.M.-P.R.	-.13	.28**	-.28**	.48**	.20**
R.T.-P.R.	.14	.37**	-.18*	.33**	.22**

P.M. = Premotor Time; M.T. = Motor Time; R.T. = Reaction Time; P.R. = Pursuit Rotor

** Significant at .01 level
* Significant at .05 level

Discussion

Performance

While performing the pursuit rotor, a number of factors are present that may influence the performance of the task. Within the framework of this study, two such factors can be identified; some degree of physical fatigue and some degree of reactive inhibition. These two factors combine to influence the performance of the task. The concept of reactive inhibition was first proposed by Clark Hull (Kleinman, 1983). According to the theory, performance is dependent upon levels of positive and negative drive states. The negative drive state was referred to as reactive inhibition, which was described as a negative, fatigue-like drive that accumulates with work (Kleinman, 1983). According to Sage (1977) Hull described reactive inhibition by stating that "whenever any reaction is evoked in an organism, there is left a condition or state which acts as a primary, negative motivation in that it has an innate capacity to produce a cessation of the activity which produced the state" (p. 401). Reactive Inhibition can be viewed then as a buildup within the individual of a negative motivation to continue. As the practise session continues more reactive inhibition is built up and the drive not to continue responding to the task becomes stronger (Sage, 1977). Kleinman (1983) claims that superior performers are characterized by high levels of learning and motivation and by very low levels of reactive inhibition. The more motivated the learners, the longer they can practise without accumulating excess levels of reactive inhibition. Conversely, subjects of low motivation and little knowledge are highly prone to accumulating reactive inhibition.

The individualization of reactions to the performance of the pursuit rotor was illustrated in a study by Nelso and Peta (1978). The authors reported that the reasons subjects terminated their performance on the pursuit were "boredom, tiredness, nervousness, pain and loss of coordination" (p. 24). Reports of a given subject were "clearly dominated by one or two types of complaints, that is, ten subjects made reference almost exclusively to muscular distress, complaints of pain in the arm, neck, shoulder, wrist and back. Five subjects complained about perceived tiredness. The most persistent concern for one subject was perceived decline in ability" (p. 25). According to the authors, physical fatigue that is experienced from work involves some type of perceptual restriction. They suggest that when the demands of the task are easily met, boredom is characteristic; however when the situation demands effort, fatigue is the primary consideration. According to the authors, fatigue is under partial control of physiological and behavioural changes. These changes are developing at different rates, and the individual attends to these changes at different times. The attention of the individual is dependent upon factors such as "learned focus of attentions, perceived task and perceived situational variables (p. 27). Subjects within a study would respond in a different manner and at a different time to the reactive inhibition. This would create a great deal of variability in response. Nelso and Peta (1978) reported a great deal of difference in "durability between seemingly similar subjects" (p. 27).

The suggestions and findings of Nelso and Peta (1978) offer an explanation for the wide response variability of the present study. It is apparent from the regression analysis that the subjects within this study exhibited a great deal of variability as to how they responded to the exercise condition. It could be argued that the subjects are responding to the task in an individual manner in keeping with the findings of Nelso and Peta (1978). Some subjects are more motivated and perform better. Some are less motivated and perform poorly. For some subjects the fatigue plus the reactive inhibition enhances performance while for others the fatigue plus reactive inhibition results in poor performance.

The present study is very similar to a study by Williams & Singer (1975). Both studies used the pursuit-rotor, both induced fatigue with a modified bicycle ergometer, and both studies failed to show fatigue to affect performance. In the Williams & Singer (1975) study subjects were required to hand crank the bicycle ergometer for five to seven minutes prior to starting the learning task and returned to the bicycle for fifteen seconds between performance trials. The added three to five minutes of exercise was not sufficient to create a decrement in performance. The authors did report the appearance of an inverted-U relationship, but the differences between groups were not significant. It can be argued that to create differences a higher level of fatigue, or a different task, or a better controlled motivation level may be required.

Other studies that have used the pursuit rotor as the criterion task have been successful in finding a significant difference between the control and fatigue groups with respect to performance. However the increased level of fatigue used in these studies likely accounts for the findings. Alderman (1965) used one fatigue bout that lasted for ten minutes. It was reported that the subjects worked at a cadence of 120 rpm at a resistance of 3.45 kilograms compared to the present study with the 60% group working at 341 kpm/min for two minutes. See Table 11 in Appendix A for other work levels. It is obvious that the subjects in the Alderman (1965) study performed more total work.

Carron (1969), in another study using the pursuit-rotor, fatigued subjects using 200 kpm/min of work for five minutes or until exhaustion. The fatigue was induced once and resulted in a significant decrease in the performance of the pursuit-rotor. Other studies such as Godwin and Schmidt

(1969), Carron and Ferchuck (1971) and Schmidt (1969) reported a performance decrease. However, the level of fatigue used was greater than in the present study.

As well as higher fatigue levels, these latter studies used differing performance tasks, which suggests a task specificity. For the performance of tasks such as the Bachman Ladder Climb, and stabilometer it can be assumed that feedback from the performing muscles is necessary for the successful completion of the task. It has been suggested (Fox & Mathews, 1981) that a muscle group may fatigue because of failure of one or all of the neuromuscular mechanisms involved in muscular contraction. One of these mechanisms that may affect the use of feedback is the role of a central-nervous system component in local muscular fatigue. It is proposed that "as a muscle fatigues, the local disturbances that occur within its initial environment are signaled back to the central nervous system (brain) via sensory nerves. In turn, the brain sends out inhibitory signals to the nerve cells in the motor system, resulting in declining muscular work output " (p. 108). It may be possible that the inhibitory signals sent out by the brain hinder or interfere with the use of the kinesthetic feedback. However, the reliance on feedback for the performance of a tracking task, according to Schmidt (1982), has not been demonstrated as being of critical importance. In light of this when performing a tracking task, the primary feedback source appears to be vision and not kinesthetic (Schmidt, 1982). There is no reason to assume that fatigue would affect vision. However, the reliance on vision for the pursuit rotor would be affected by reactive inhibition. While the fatigue was not of enough intensity to create physiological difficulties, when combined with reactive inhibition may have created boredom and/or lack of attention, resulting in a loss of concentration. With the importance of visual input in the tracking task, this would result in the subject not attending to the visual cues. Based on the individual nature of the reactive inhibition, the result would be very inconsistent performance within the fatigue group.

Schmidt (1982) has also suggested that for simple tasks (such as the pursuit rotor) the individual can perform the task in a program mode, and pay little attention to the task. In essence what could happen is the individual could just be going through the motions of the pursuit-rotor and not attending to the accuracy requirements of the task, with the result being poor scores. However, as the fatigue level increases, the arousal level of the individual performer also increases, resulting in an increased level of attention. It was observed within the 80% fatigue group that the variability between subjects was less than that observed in the other fatigue groups.

The concept of perceptual narrowing may best explain the apparent reduction in variability within the 80% group. Perceptual narrowing suggests that as arousal increases there is a narrowing of attentional focus, with a progressive elimination of input from more peripheral aspects of the environment (Schmidt, 1982).

As arousal level increases, selective attention directs capacity toward these sources of information that are most meaningful and we tend to ignore those events that are judged as irrelevant. Because of the simple nature of the task, a relatively high level of fatigue or arousal is necessary to overcome reactive inhibition, with the resulting consistency of performance. The more demanding the task, the more challenging the task, the higher level of interest the subjects may possess.

Within the present study, subjects in the mild and moderate fatigue levels displayed a wide variability of performance. It appears that the reactive inhibition plus the fatigue present resulted in facilitation in performance for some subjects and interfered in performance for others. However, in the 80% fatigue group the perceptual narrowing plus the fatigue level may have offset the effect of reactive inhibition resulting in a more consistent performance.

Learning

Previous studies that have found fatigue to affect learning have used severe levels of fatigue resulting in both performance and learning decreases. Authors of these studies have reported that the fatiguing tasks were of such a level that many subjects were unable to complete them. It appears from the findings of these studies that for learning to be affected, the fatigue must affect performance. Within the present study, the fatigue was not of a severe enough intensity to affect the performance of the pursuit-rotor and as a result learning was not altered. While the insufficient fatigue level probably accounts for the lack of significant learning effects the type of task used may also be a contributing variable. According to Schmidt (1982) an individual learns a skill by developing a motor program through repeated performances of the task. This program is stored in a generalized form in memory. The idea of a generalized motor program was developed because of the impossibility of storing a separate program for each activity and as an explanation for the ability of an individual to respond to a novel task with a new movement. This program is termed general because "the program's output in terms of movements of the limbs can be altered somewhat according to the parameters chosen on a particular trial, the program is said to be generalized" (p. 304). In order to execute the generalized program, the performer must specify one or more of the following parameters: duration (speed) parameter, overall force parameter, spatial parameter, and the movement size parameter.

Within the current study, the subjects were required to hand crank the bicycle ergometer prior to performing the pursuit-rotor task. In the performance of the fatiguing exercise the subjects were going through the approximate motions that would be required in performing the pursuit-rotor. This would afford them the opportunity to develop the generalized motor program. Further, the speed of the bicycle ergometer was the same as the speed of the pursuit rotor task. As well, the movement size, required for performing the exercise task was the same as the pursuit-rotor. Both of these variables are parameters required in the performance of the pursuit-rotor. It may be argued that the individual was able to transfer the generalized motor program, developed while performing the bicycle exercise, to the performance of the pursuit-rotor. This transfer effect may also involve the transferring of the speed and movement size parameter necessary to put the program into action.

Studies that have found fatigue to affect learning have generally used more complex and physically demanding motor tasks than the pursuit-rotor. As well, the fatiguing tasks used in these studies were not related to the criterion tasks, therefore not providing an opportunity for the subjects to develop a motor program. As a task becomes more complex,more emphasis is placed upon attentional demands and the use of feedback for the controlling of the performance. As the task complexity increases, so does the possibility that fatigue may affect the development of the motor program.

Developing a motor program for a more complex task requires more interplay between the parameters of the program. The program for a complex task is much more complicated and relies on a higher integration of movements than a simpler task. The Schema Theory suggests that after a movement is made the individual briefly stores four variables; the initial conditions, parameters assigned to the generalized motor program, the outcome of the movement, and the sensory consequences. These four sources of information are not stored permanently but only long enough so the performer can abstract some relationship from them. From this relationship, two schemas are formed, a recall schema, and a recognition schema.

The recall schema is concerned with the production of movements. On the basis of this schema the individual makes decisions as to the type of movement outcome desired and selects the parameters that will likely accomplish the desired task. The recognition schema is used to determine whether the movement that is produced is correct.

By severely physically fatiguing the individual, the ability to extract relationships from the information generated from the movement may be reduced. Under severe fatigue the individual would not be able to shape the program. If a response occurs and one of the four elements necessary for developing relationships is missing, the result would be a reduction in the learning. Inability to perform a task would result in missing parameters and thus reduced learning.

An examination of figure 1 reveals the appearance of a reminiscence effect. Reminiscence is a "phenomenon in which performance increases after a rest interval and is therefore attributable to rest (Singer, 1975, p. 459). The reminiscence effect is believed to occur only when the task has been partially learned. While the reminiscence effect within this study was observed for all fatigue groups, statistical analysis found the effect to be only significant for the control group. However, the large variability existing within the fatigue groups probably accounts for the lack of significant differences.

In summary, the results of this study failed to show significant differences in performance and learning as a result of the fatigue treatments. Graphical representation of the data only revealed slight evidence for the existence of an an inverted U relationship for performance. It has been suggested that the relationship between performance and learning is also an inverted U, (Williams & Singer, 1975), but the findings of this study do not support this position.

It was found that there was a great deal of subject variability within fatigue groups. This author suggested that reactive inhibition plus the mild or moderate fatigue levels resulted in improvement in some subjects and no improvement in others. Subjects in the 80% fatigue group did not show the wide variability found in the other fatigue groups. It was suggested by this writer that the higher level of fatigue plus perceptual narrowing, offset the reactive inhibition present, creating improvement in all subjects. It appears from the findings of this study to affect the performance of the pursuit rotor a more severe level of fatigue is required.

Studies that have found learning to be affected by fatigue have reported the use severe levels of fatigue. In the current study it appears the insufficient fatigue intensity caused the lack of learning effect, however the type of task used and the method of inducing fatigue may also be contributing factors. It was suggested that by fatiguing the subjects on the bicycle ergometer, using a pattern identical to the pursuit-rotor, the development of a generalized motor program was possible. The individual would then be able to transfer the generalized motor program developed during the fatiguing task to the performance of the pursuit-rotor.

Reaction Time

The purpose of measuring the effect of fatigue upon reaction time was to determine if a relationship exists between performance and reaction speed under various levels of fatigue. It has been suggested that one of the causes of a decrease in performance as a result of fatigue may be the effect fatigue has on reaction time, essentially the processing of information (Wood, 1979). If a decrease in performance of a motor task is observed, and it correlates highly with changes in reaction time due to the fatigue, this correlation may assist in finding an explanation for the effect fatigue has on performance.

It could be argued that if performance of the pursuit-rotor and reaction time are related a decrease in performance would be accompanied by an increase in reaction time suggesting a slowing of processing speed. Within the current study no significant fatigue effects with respect to performance were observed but rather all groups displayed a significant improvement in performance over the twenty-eight trials. Examination of the correlation values (Table 7) did not reveal a strong correlation. The only negative coefficient that existed was within the 40% fatigue group, but while the correlation was significant, it was very low. There appears from the other correlations to be a tendency for reaction time to increase as pursuit rotor scores increase.

Correlation between motor time and pursuit-rotor for the control group indicates a relatively high significant correlation. This indicates tendency for motor time to increase as a pursuit-rotor scores increase. The 25% and 40% fatigue groups also revealed positive significant correlations between motor time and pursuit rotor, however the correlations were relatively low. A negative coefficient of -.30 was observed for the 60% group indicating that as performance increases, reaction time decreases. This is opposite from what was found in the other three groups. The 80% fatigue group revealed a correlation of .01, almost no correlation at all. No consistent relationship between motor time and pursuit-rotor is evident in the various groups. This inconsistency was also apparent for the correlations between pre-motor and pursuit-rotor values. Levitt and Gutin (1971) and Bender and McGlynn (1976) have suggested that under mild levels of fatigue, reaction time would decrease, and under more severe levels it would increase. Mean 2, in Table 6 representing the five reaction time score following the two minute fatigue task, shows that the 25% fatigue group had an improved score as compared to the control group, with a subsequent increase in reaction time for the 40% and 60% fatigue groups. These findings are similar to the previous authors findings. However, in the current study, the 80% fatigue group had the fastest reaction time at mean 2, and this finding is in contrast to the previous studies.

Authors such as Kroll (1974), Hayes (1975) and Klimovitch (1977) and others have suggested the existence of a threshold level, where fatigue under a certain intensity will not affect reaction time, but once fatigue reaches a criterion level, reaction time would increase. However, this phenomenon is not apparent in the current study. It could be argued that the most fatigue being experienced by the subjects would be occurring during mean 5. However, it appears from the graph that the reaction time values consistently improve across the fatigue groups. These scores appear to be displaying a warm-up effect.

It is apparent from the results of this study that there is no consistent relationships between performance and reaction time scores. Correlation of reaction time scores with pursuit rotor performance scores did not bring out a clear pattern. The two variables appear to act independently of each other, as is evident from the low correlations. For the purpose of this study, the reaction time effects did not provide an aid in the explanation of the observed performance effects.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine whether the inverted U model adequately represents the effects of fatigue upon performance and learning. It was also investigated whether a relationship exists between the effects of fatigue on performance and learning and the effect of fatigue on reaction time. Thirty-five male subjects were randomly assigned to one of five groups, a control and four experimental groups. Three pre-test reaction time and pursuit rotor trials were given, followed by two minutes of hand cranking a bicycle ergometer at a pre-set resistance level. Fifteen seconds of exercise was interpolated between consecutive performance and reaction time trials. A total of twenty fatigue trials were completed. A further five pursuit-rotor trials were conducted under non-fatigue conditions, forty-eight hours after the fatigue tests.

The performance data revealed no significant fatigue effect between groups, and graphical presentation of the data only revealed slight evidence for th existence of an inverted U relationship. Performance data also revealed a wide subject variability, most pronounced within the 40% and 60% fatigue groups. No significant fatigue effects were found for the learning data, indicating no impairment of learning occurred due to fatigue. A reminiscence effect was shown for all groups, but it only reached of significance within the control group. No strong correlation between fatigue effects on performance and fatigue effects were found, indicating that a causal relationship was not apparent.

The study's finding of a weak inverted U relationship with respect to fatigue and performance offers little support for the use of this model to explain fatigue effects. The lack of significant differences is in agreement with the findings of Williams & Singer (1975) and may suggest the existence of a threshold level of fatigue beyond which pursuit-rotor performance is altered. Other pursuit-rotor studies that have found fatigue affects have used more intense fatigue levels. As well, other studies finding fatigue effects have used different motor skills, suggesting a task specificity.

A wide subject variability within fatigue groups particularly the 40% and 60% groups was observed, and it was suggested that fatigue plus reactive inhibition may account for this finding. Less variability was observed within the 80% fatigue group and it was suggested the perceptual narrowing may account for this change.

No inverted U relationship was found with respect to fatigue and learning. Previous studies that have found learning to be impaired have used higher fatigue levels and have also reported significant fatigue effects with respect to performance as well as learning. It was also suggested that other factors as well as the insufficient fatigue level may contribute to the ability of the subjects to learn the pursuit-rotor. While performing the fatiguing task, the development of the general motor program may have occurred, complete with the movement size and speed parameters necessary for the completion of the task. The general motor program could then be transferred to the performance of the pursuit-rotor. Previous studies that have found fatigue and learning effects have generally used more complex motor tasks, with a greater possibility that fatigue would interrupt the development of the recall and recognition schemas.

It appears, based on the results of this study, that the two variables act independently of each other. There appears to be no relationship between fatigue effects on the pursuit rotor and fatigue effects on reaction time.

Recommendations

1. Upon completion of the testing, a large variability between subjects was observed. One of the causes of the variability may be a lack of motivation by the

subjects to respond to the task with their best efforts. It is therefore suggested that future studies employ some type of motivational technique.

2. Research to date has dealt primarily with fatigue and performance and learning, with no attempt to classify the type of motor task; such as continuous vs discrete. Research findings appear to be indicating the existence of task specificity. This author suggests that further research begin to classify motor skills and examine how fatigue effects the different motor skill classifications.

3. One of the goals of fatigue and performance studies is to determine what aspect or aspects of performance are influenced by fatigue. Within the current study an effort was made to find a relationship between performance and reaction time. Future studies should continue to include variables of performance in an effort to better understand the causes of observed performance effects.

4. Currently, the mechanism of fatigue is not well understood. Further study of the physiology of fatigue is needed. New findings with respect to fatigue must then be applied to performance and learning studies. Researchers in the area of fatigue and researchers in the field of motor learning must begin to work together on joint projects to further the understanding of the effect of fatigue on performance and learning.

BIBLIOGRAPHY

Alderman, R. B. Influence of local fatigue on speed and accuracy in motor learning. Research Quarterly, 1965, 36, (2), 131-140.

Asmussen, E. Muscle fatigue. Medicine and Science in Sports, 1979, 11, (4), 313-321.

Bender, V. L., & McGlynn, G. H. The effect of various levels of strenuous to exhaustive exercise on reaction time. European Journal of Applied Physiology, 1976, 35, 95-101.

Benson, D. W. Influence of imposed fatigue on learning a jumping task and a juggling task. Research Quarterly, 1968, 39, (2), 250-257.

Carron, A. V. Physical fatigue and motor learning. Research Quarterly, 1969, 40, (4), 682-686.

Carron, A. V. Motor Performance and learning under physical fatigue. Medicine and Science in Sports and Exercise, 1972, 4 (2), 101-106.

Carron, A. V., & Ferchuck, A. D. Effect of fatigue on learning and performance of a gross motor task. Journal of Motor Behavior, 1971, 3 (1), 62-68.

Cochran, B. J. Effects of physical fatigue on learning to perform a novel motor task. Research Quarterly, 1975, 46 (2), 243-249.

Cotten, D. J., Spieth, W. R., Thomas, J. R., & Biasiotto, J. L. Local and total body fatigue effects on learning and performance of a gross motor skill. Medicine and Science in Sports and Exercise, 1974, 6 (2), 151-153.

Fox, E. L., & Mathews, D. K. The physiological basis of Physical Education and Athletics (3rd Ed.). Philadelphia, Pa.: Saunders College, 1981.

Godwin, M. A., & Schmidt, R. A. Muscular fatigue and learning a discrete motor skill. Research Quarterly, 1971, 42, (4), 374-382.

Gutin, B. Exercise induced activation and human performance: A review. Research Quarterly, 1973, 44, 256-268.

Hanson, C., & Lofthus, G. Effects of fatigue and laterality on fractionated reaction time. Journal of Motor Behavior, 1978, 10, (3), 177-184.

Hayes, K. C. Effects of fatiguing isometric exercise upon achillles tendon reflex and plantar flexion reaction time components in man. European Journal of Applied Physiology, 1975, 34, 69-79.

Kamen, G., Kroll, W., Clarkson, P. M., & Zigon, S. T. Fractionated reaction time in power-trained and endurance trained athletes under conditions of fatiguing isometric exercise. Journal of Motor Behavior, 1981, 13 (2), 117-129.

Kleinman, M. The Acquisition of Motor Skill. Princeton, N.J.: Princeton Book Co., 1983.

Klimovitch, G. Startle response and muscular fatigue effects upon fractionated hand grip reaction time. Journal of Motor Behavior, 1977, 9 (4), 285-292.

Kroll, W. Effects of local muscular fatigue due to isotonic and isometric exercise upon fractionated reaction time components. Journal of Motor Behavior, 1973, 5 (2), 81-93.

Kroll, W. Fractionated reaction and reflex time before and after fatiguing isotonic exercise. Medicine and Science in Sports, 1974, 6 (4), 260-266.

Lamb, D. P. Physiology of Exercise. New York: MacMillan Publishing Company, 1978.

Levitt, S., & Gutin, B. Multiple choice reaction time and movement time during physical exertion. The Research Quarterly, 1971, 42 (4), 405-409.

Lofthus, G. , & Hanson, C. The influence of laterality and fatigue upon the performance of a two handed reaction task. The Research Quarterly, 1980, 51, (3), 501-508.

Morris, A. F. Effect of fatiguing isometric and isotonic exercise on resisted and unresisted reaction time components. European Journal of Applied Physiology, 1977, 37, 1-11.

Nelso, T. M., & Peta, L. Endurance and Experience of Paced Motor Activity. Waking and Sleeping, 1978, 2, 21-28.

Pack, D. M., Cotten, D. J., & Biasiotto, J. Effect of four fatigue levels on peformance and learning of a novel dynamic balance task. Journal of Motor Behavior, 1974, 6 (3), 191-197.

Sage, G. H. Introduction to Motor Behavior A Neuropsychological Approach (2nd ed.). Reading Mass.: Addison-Wesley Publishing Co., 1977.

Schmidt, R. A. Motor Control and Learning. A Behavioral Emphasis (1st ed.). Champaign, Ill.: Human Kinetic Publishers, Inc., 1982.

Schmidt, R. A. Performance and learning a gross-motor skill under conditions of artificially-induced fatigue. Research Quarterly, 1969, 40, (1), 185-189.

Sheerer, N., & Berger, R. A. Effects of various levels of fatigue on reaction time and movement time. American Corrective Therapy Journal, 1972, 5, 1972.

Singer, P. N. Learning and Human Performance (3rd ed.). New York: Macmillan Publishing Company, 1980.

Stull, G. A., & Kearney, J. T. Effects of variable fatigue levels on reaction-time components. Journal of Motor Behavior, 1978, 10, (30), 223-231.

Thomas, J. R., Doyice, J. C., Spieth, W. R., & Abraham, W. L. Effects of fatigue on stabilometer performance. Medicine and Science in Sports, 1975, 7 (3), 203-206.

Weiss, A. D. The locus of reaction time changes with set, motivation, and age. Journal of Gerontology, 1965, 20, 60-64.

Williams, J., & Singer, R. N. Muscular fatigue and the learning and performance of a motor control task. Journal of Motor Performance, 1975, 7 (4), 265-269.

Wood, G. A. Electrophysiological correlates of local muscular fatigue effects upon human visual reaction time. European Journal of Applied Physiology, 1979, 41, 247-257.

APPENDICES

Appendix A

Table 10

Trial Means and Standard Deviations for Performance Scores

Trial	Control		25%		40%		60%		80%	
	x	S.D.	x̄	S.D.	x̄	S.D.	x̄	S.D.	x̄	S.D.
1	3.36	1.03	3.17	1.05	3.33	1.33	3.27	1.44	2.91	1.06
2	4.41	.77	4.82	1.40	5.23	1.72	4.74	1.73	4.68	1.50
3	4.61	1.24	4.56	1.71	5.62	2.08	4.90	1.45	4.86	1.40
4	5.41	1.18	5.58	2.41	5.09	2.04	4.17	1.36	4.66	.83
5	6.15	.92	5.32	1.43	6.48	1.65	5.78	1.79	5.86	1.34
6	5.36	1.95	7.03	1.94	6.31	1.49	6.96	3.18	5.62	1.17
7	6.91	1.59	6.19	1.62	6.65	1.93	5.72	2.43	6.59	1.03
8	6.55	.94	6.50	2.60	7.74	1.70	5.92	1.48	6.40	1.04
9	6.04	.83	5.55	1.73	6.23	2.34	5.92	2.09	6.22	.66
10	6.90	1.23	6.05	2.47	6.95	1.76	6.23	2.05	6.31	1.10
11	6.34	.89	6.10	1.90	6.69	2.28	6.28	1.58	6.56	1.24
12	6.56	.80	7.15	2.02	6.59	2.38	6.13	2.34	6.45	.84
13	7.13	1.61	6.77	2.04	6.51	2.51	6.62	1.79	6.90	.57
14	6.56	1.14	7.16	1.53	6.87	2.94	6.06	1.00	6.94	.99
15	6.39	1.20	7.79	1.22	7.55	2.27	5.79	1.40	7.20	.72
16	7.32	1.20	7.48	1.75	6.85	2.52	6.09	1.21	7.19	.86
17	6.97	.50	7.56	1.73	7.03	2.27	6.22	1.56	7.17	1.34
18	7.77	.86	7.21	1.41	7.53	3.00	6.32	1.67	6.69	1.27
19	7.07	1.04	7.45	1.99	6.73	2.65	5.94	1.49	7.72	1.29
20	6.35	1.12	7.82	1.18	7.54	2.71	6.30	1.69	7.59	1.57
21	6.75	1.99	7.16	1.38	6.98	2.63	6.96	2.09	6.46	1.44
22	6.79	.81	7.65	1.74	7.70	2.34	6.91	1.79	7.35	1.20
23	7.38	1.14	7.79	1.61	7.79	2.43	7.06	1.73	6.67	1.15
24	7.04	.85	7.45	1.59	8.68	.70	7.54	1.55	8.11	1.17
25	8.09	1.25	7.91	.73	8.77	2.40	7.77	1.38	9.94	.70
26	8.72	1.08	7.86	2.09	9.07	1.78	7.63	.67	7.98	.91
27	8.50	1.29	7.66	.62	8.54	2.02	7.96	1.50	7.96	.53
28	8.68	.86	8.63	1.10	8.49	1.91	7.67	1.31	7.76	.55

Table 11

Exercise Workloads by Fatigue Group (Kpm/min)

	Fatigue Groups			
Subjects	25%	40%	60%	80%
1	135	240	360	564
2	150	240	360	450
3	150	300	395	480
4	150	240	315	480
5	180	240	330	480
6	165	225	315	480
7	150	180	315	540
mean	154.29	237.86	341.43	496.28
Standard Deviation	14.26	35.10	31.05	40.21

Appendix B

EFFECTS OF INDUCING LOCALIZED MUSCULAR FATIGUE ON THE PURSUIT ROTOR TASK

EFFECTS OF INDUCING LOCALIZED MUSCULAR FATIGUE ON THE PURSUIT ROTOR TASK

Consent Form

The purpose of this study is to measure the effect hand cranking a bicycle ergometer has on the performance and learning of a pursuit-rotor task and on the performance of a reaction time task.

The testing is conducted over a three-day period, as follows:

1. Pre-test: You will be asked to hand crank a modified bicycle ergometer for two minutes at fifty revolutions per minute. You will first perform the task with your left arm and then with your right arm. The resistance will be set by the experimenter and should be of such an intensity that you will be unable to continue cranking after the two minutes.

2. Testing: Three surface electrodes will be placed on your triceps muscle. You will be seated on a stool and asked to perform three, twenty-second pursuit rotor trials and three reaction time trials. The mechanics for these two tests will be verbally explained to you and a demonstration given. You will then be asked to hand crank the bicycle ergometer at fifty revolutions per minute for two minutes. You will then be asked to peform a reaction time trial and a pursuit rotor trial. You will then return to the bicycle for a fifteen second trial, again followed by a reaction time trial and a pursuit-rotor trial. This procedure will continue until twenty-three trials are completed.

3. Post-Test: You will be asked to return forty-eight hours after the testing day to perform five pursuit-rotor trials.

Risks and Discomforts: All tests performed are non-intrusive tests. The performance required will be at or below maximal local capacity. Following both the pre-test and the actual testing some fatigue will be experienced in the shoulder. This fatigue will dissipate in a few hours.

Inquiries: If you have any questions regarding any aspect of this study, its procedures or any of the explanations given to you, feel free to ask.

I have read and understood the above explanations of the purpose and procedures for this study and agree to participate. I also understand that I am free to withdraw my consent at any time.

____
Signature

____________________________ Witness

____
Date

Appendix C

REACTION TIME RECORDING ATTACHMENT FOR ELECTROCARDIOGRAPH MODEL VS-4

Reaction Time Recording Attachment For Electrocardiograph Model VS-4