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The effect of a specific respiration pattern on running efficiency and ventilation parameters of skilled distance runners

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THE EFFECT OF A SPECIFIC RESPIRATION PATTERN ON RUNNING EFFICIENCY AND VENTILATION PARAMETERS OF SKILLED DISTANCE RUNNERS

By

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ABSTRACT

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This study investigated the effects of a controlled respiration pattern on the running performance and ventilation considerations of skilled distance runners.

A pilot study was conducted in which six male subjects practiced the controlled respiration pattern.

The subjects completed four treadmill tests; two each at 9.75 miles per hour (6:09 minute mile pace) and 12.75 miles per hour (4:42 minute mile pace) using the controlled pattern for one test and uncontrolled (natural) breathing pattern for the other test. Breathing parameters measured were: total ventilation, oxygen uptake, volume of carbon dioxide, respiratory quotient, heart rate, percentage of oxygen used, and percentage of carbon dioxide expired. Video tapes of each test were recorded to count the number of strides and breaths taken. Each subject was tested on a random assignment of test order.

There were no statistically significant differences in running efficiency and in the ventilatory parameters measured in this study between the controlled breathing pattern tests and the uncontrolled tests or between the individual time segments of those tests.

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TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGEMENTS iii

LIST OF TABLES vi

LIST OF FIGURES vii

Chapter

1. INTRODUCTION 1

    PROBLEM 2

    LIMITATIONS 2

    DEFINITIONS 3

    HYPOTHESIS 4

2. LITERATURE REVIEW 5

3. METHOD 12

    PILOT STUDY 22

    PROCEDURE 23

        SUBJECTS 23

        APPARATUS 23

        DESIGN 25

        DATA ANALYSIS 29

4. ANALYSIS OF RESULTS 31

    MODERATE INTENSITY TESTS 31

    HIGH INTENSITY TESTS 42

5. DISCUSSION, RECOMMENDATIONS AND SUMMARY 57

    DISCUSSION 57

Chapter Page

RECOMMENDATIONS 61

SUMMARY 62

REFERENCES 63

APPENDICES 66

A: INFORMED CONSENT FORM 66

B: BIOGRAPHICAL DATA FORM AND RESPONSES 67

C: VENTILATION PARAMETERS TABULATION SHEET 69

D: HEART RATE & BREATHS TABULATION SHEET 70

E: RATIO OF STRIDES TO BREATHS FOR EACH SUBJECT DURING EACH 30 SECOND SEGMENT 71

LIST OF TABLES

Table Page

1. Characteristics of Subjects 24

2. Total Ventilation (V_E ml/min) per time segment. 32

3. Oxygen Uptake (VO_2 ml/min/kg) per time segment. 33

4. Volume of Carbon Dioxide (VCO_2 ml/min) per time segment . 34

5. Respiratory Quotient per time segment 35

6. Percentage of Carbon Dioxide Expired (%CO_2) per time segment 36

7. Percentage of Oxygen Used (%O_2) per time segment 37

8. Heart Rate (beats per minute) per time segment 38

9. Number of Strides taken during each test per time segment 39

10. Number of Breaths taken during each test per time segment 40

11. Ratio of Strides per Breaths for each test per time segment 41

12. Total Ventilation 45

13. Oxygen Uptake 46

14. Volume of Carbon Dioxide 47

15. Respiratory Quotient 48

16. Percentage of Carbon Dioxide 50

17. Percentage of Oxygen 51

18. Heart Rate 52

19. Number of Strides taken during each test 53

20. Number of Breaths taken during each test 54

21. Ratio of strides per breaths for each test 55

22. Data for all variables from all tests 56

LIST OF FIGURES

Figure Page

1. Beckman Metabolic Measurement Apparatus and a subject hooked to the apparatus 26

2. Quantum XL Heart Rate Monitor as worn by the subjects . . 27

3. Lab set up of the video camera and mirror 28

Chapter 1

INTRODUCTION

Interest in the phenomenon of respiration and its effects on human functioning has increased the last few years. In the last year the popular literature has widely publicized the importance and benefits of conscious respiration (Perry, 1985; Plunkett, 1986; Jackson, 1986; and Zi, 1986). In the psychophysiological literature respiration has been greatly neglected. Traditionally, cardiovascular psychophysiologists have chosen to treat respiration as a nuisance variable, often not controlling for it or only making cursory attempts to do so (Grossman, 1983). Runners tend to have the same idea about breathing, letting breath patterns evolve unconsciously and automatically; "sucking" in air as it is needed (Plunkett, 1986). Recently attention has been focused on respiration and the influence controlled breathing can have on an individual's life; mentally, physically, and emotionally (Grossman, 1983; Jackson, 1986; Plunkett, 1986; and Zi, 1986).

Authorities are beginning to reexamine this natural, involuntary human function, respiration, in new perspectives to enhance human performance and psychological and physiological well being (Grossman, 1983; Clark et al, 1983; and Bell, 1980). Jackson, who feels that most runners do not breathe properly, outlines a systematic approach to breathing by using a series of specific skills designed to help aerobic athletes control respiration to maximize their performance (Plunkett, 1986; Jackson, 1986). It is appropriate to examine the effects of a conscious change in the respiration patterns of highly skilled athletes.

PROBLEM

The purpose of this study was to measure the effect of a specific respiration pattern on running performance and oxygen consumption for skilled distance runners. The performance criterion was the length of time the athlete could continue the respiration and stride pattern and the amount of oxygen consumed for a set workload. Two different workloads were used to compare the effectiveness of the respiration pattern at different intensity levels. Oxygen consumption was measured to report the efficacy of the controlled respiration pattern.

LIMITATIONS

This study contained limitations common to many studies involving varsity athletes. The investigator had to work within the constraints of the track coach and the athletes school schedule, practice schedule, and competition schedule.

1) The subjects were chosen and placed in each study group. Because of an experimental design requiring a pilot study, the sample group was defined, due to their prior experience with the specific respiration pattern.

2) The subjects were not equal in knowledge and experience with the task. The subjects' structured practice time during the pilot study ranged from 10-18 minutes per session for a range of one hour to two-and-one-half hours total time.

3) During the interim period of the pilot study and the present study, the amount of practice time on the task by each subject was unknown.

DEFINITIONS

The following terms are defined as to their meanings in this study.

Energy Cost, the amount of oxygen consumed for a specific amount of work.

Ventilation, ... in physiology, the amount of air inhaled per unit of time.

Dyspnea, short of breath, difficult or labored respiration.

Hyperpnea, abnormally rapid or deep breathing.

Forced Respiration, voluntary hyperpnea (increase in rate and depth of breathing).

Muscles of Respiration,
  Inspiration = diaphragm and external intercostals.
  Forced Inspiration = (assist in elevating ribs and sternum) scaleni, levatores costorum, sternocleidomastoideus, pectoralis major, platysma myoides, and serratus posterior superior.
  Expiration = (voluntary deep breathing or forced expiration) rectus abdominis, external and internal oblique, transverse abdominis.

Respiratory Quotient, the relation of CO_2 produced and O_2 consumed; e.g.: $CO_2 \div O_2$.

Apnea, temporary cessation of breathing. May result from reduction in stimuli to the respiratory center, as in overbreathing, in which CO_2 content of the blood is reduced; from failure of respiratory center to discharge impulses, as when the breath is held voluntarily...

Eupnea, normal breathing as distinguished from dysonea and apnea.

Hypocarbia, decreased CO_2 in the blood. Excess rate of respiration will cause this.

Hypercapnia, increased amount of CO_2 in the blood.

Hypoxia, deficiency of O_2. Decreased concentration of O_2 in the inspired air.

Tidal Volume, the volume of gas inspired or expired during one cycle of respiration.

Minute Ventilation Volume, equals the sum of tidal volumes over one minute.

HYPOTHESES

1. The acquisition of the respiration pattern will not effect the energy cost of running.
2. There will be no difference in efficiency in the respiration patterns between the maximal and submaximal efforts.

Chapter 2

LITERATURE REVIEW

In a normal, alert human, respiratory processes exert specific influences upon various aspects of cardiovascular functioning. These respiratory processes may be greatly influenced by behavioral, emotional, and cortical factors (Grossman, 1983). Peripheral and central nervous system mechanisms may influence respiration to enable humans to employ the most efficient breathing pattern for a given exercise-induced ventilatory demand (Vidruk & Dempsey, 1980).

Grossman (1983) reviewed and attempted to integrate the experimental literature indicating the importance of respiration of cardiovascular psychophysiology. Grossman discussed three findings the recent research has shown:

1) variations in breathing pattern may often modulate cardiovascular functioning in everyday life,

2) there are large, stable individual differences in breathing pattern, and

3) variations in breathing pattern may be greatly influenced by behavioral,.emotional and cortical factors.

Physiologists have found several mechanisms of respiration that may modulate cardiovascular activity (Grossman, 1983). Four areas of major importance are: 1) mechanical effects, 2) reflex arcs between peripheral receptors and higher centers (e.g. lung inflation receptors), 3) peripheral input which may often have opposing primary and secondary effects (i.e chemoreception), and 4) input originating in the CNS itself (i.e. central respiratory activity) (Grossman, 1983).

These four areas of respiratory modulation upon cardiovascular activity are expressed through five parameters of respiration:

> <u>Breathing Frequency.</u> Variations in breathing frequency have been shown to produce inverse changes in heart rate variability independently of tidal volume.
>
> <u>Depth of Ventilation.</u> Increased depth of breathing causes augmentation of heart rate and heart rate variability, as well as generally increased blood flow to the skeletal muscles and forehead but decreased flow to the hands and feet.
>
> <u>Breath-Holding.</u> Pausing between inspiration and expiration will produce rapid and pronounced bradycardia. Twenty-beat-per-minute decelerations frequently occur within one or two beats from commencement of breath-holding. Blood flow to the brain and the heart is also enhanced during respiratory pause.
>
> <u>Muscular Mode of Ventilation.</u> Thoracic (ribcage) dominant breathing seems to produce increases in cardiac output and heart rate during inspiration and peripheral vasoconstriction, whereas abdominal (diaphragmatic) ventilation appears to induce the opposite effects.
>
> <u>Alveolar Carbon Dioxide Tension.</u> Alveolar carbon dioxide pressure has been related to a wide range of cardiovascular parameters. CO_2 influences upon vascular tone normally act to alter blood flow to the brain and the heart in relation to metabolic needs, providing for a constancy of the intracellular environment (autoregulation). Hyperventilation and eucapnic breathing patterns result in relatively low alveolar CO_2 levels causing an increase in rate and a decrease in tidal volume of breathing, as well as predominately thoracic ventilation. Increased production of CO_2 in the brain and the heart induces relaxation of vascular tone; promoting blood flow, oxygenation of tissues and removal of acidic metabolites. (Grossman, 1983)

Available research findings suggest that graded, systematic and directional cardiovascular alterations may be induced by CO_2 related respiratory changes (Grossman, 1983).

Respiratory and cardiovascular processes are bound together by independent intracentral coupling mechanisms. There exists a central integration of certain respiratory and cardiovascular processes, such that some central neurons serve both functions (Grossman, 1983). Heart rate, blood pressure and sympathetic nerve activity are increased during inspiration and decreased during expiration, and also vary along with changes in central respiratory response.

CO_2 is well known to exhibit powerful effects upon the cardiovascular system and, under many conditions, apparently serves a self-regulatory function. CO_2 influences upon vascular tone normally act to alter blood flow to the brain and the heart in relation to metabolic needs, providing for a constancy of the intracellular environment (autoregulation). Hence, increased production of CO_2 in these regions will induce relaxation of vascular tone, promoting blood flow, oxygenation of tissues and removal of acidic metabolites (Grossman, 1983).

A transient drop in blood CO_2 levels results in hyperventilation that appears to be an integral aspect of stress response. Hyperventilation may have evolved as a preparatory metabolic measure for ensuing physical action. The drop in blood CO_2 levels is quickly compensated for by augmented CO_2 production due to increased activity (Grossman, 1983). When physical action is inappropriate and not initiated, continued hyperventilation may become a disruptive physiological force, capable of disturbing various systems.

In a series of studies (Schaefer, 1958, 1979 as reported in Grossman, 1983), slow, deep breathers with relatively high alveolar CO_2 were compared to fast shallow breathers with lower CO_2 levels. The high CO_2 group was found to have slower resting heart rates, and there were indications of decreased adrenal cortical activity and overall reduced autonomic responsiveness in comparison with the low CO_2 group. This research suggested that CO_2 levels may contribute to variations in heart rate and other autonomic responses not only during hyperventilation but also during eucapnic states of ventilation (Grossman, 1983).

CO_2 levels may be one of the stimuli occurring during respiration. Muscle and joint movements also act as effectors of respiratory rates (Hardin et al, 1987).

Gary's multiple factor theory of the control of respiration states that: "Although a number of factors exert independent effects on respiratory ventilation, the total effect is determined by the algebraic sum of the partial effects of the separate agents". Several studies have been completed on experimental animals and on human subjects in an attempt to resolve the question of respiratory control during rest and exercise (as reported in Hardin et al, 1987).

Dejours (1963) attributes the initial rise in ventilation rate to neural causes but the later increase to chemical substances in the blood. Hey et al (1966) reported that in mild exercise, frequency (f) was often a submultiple of the number of strides per minute.

Vidruk & Dempsey (1980) reviewed some of the peripheral and central nervous system mechanisms that may enable humans to employ the most efficient breathing pattern for a given exercise-induced ventilatory demand. All of the studies reviewed, indicated that the ventilatory patterns naturally favored were the least costly ones in terms of energy expenditure.

One series of experiments (Grimby et al, 1968; Grimby et al, 1971; Konno & Mead, 1967 as reported in Vidruk & Dempsey, 1980) aimed at examining breathing patterns both at rest and during exercise demonstrated that the main muscle of breathing under these conditions is the diaphragm. A major implication from these studies was that breathing is most efficient when it maximally utilizes the diaphragm.

A mechanically advantageous range of lung volumes is accomplished by retention of a functional residual capacity (FRC) which changes very little from the resting level during exercise despite the occurrence of a substantial increase in end inspiratory volume. Despite the increased inspiratory volume, active expiration is sufficient to return the lung to near FRC, but this requires an additional increment of energy expenditure by expiratory muscles (Vidruk & Dempsey, 1980).

It is important to note that virtually all normal motor skills, of which breathing is an example, are apparently governed by one of the oldest principles in theoretical science - the principal of minimal effort (Vidruk & Dempsey, 1980). According to MacConaill & Basmajian (1969 as reported in Vidruk & Dempsey, 1980), movement becomes as efficient as possible through a learning process that employs selective inhibition of musculature not essentially involved in the movement.

The exercise stimulus could activate a process which applies the principle of minimal effort to exercise hyperpnea. A generally accepted concept of the control of skeletal muscle involves the idea that many movements such as those employed in locomotion are initiated by a specific pattern of discharge within a central nervous system network of neurons (Vidruk & Dempsey, 1980). These movements can be altered by sensory feedback from involved muscles (peripheral feedback) as well as by inputs from other loci in the CNS. The sensory innervation of the muscles of breathing as well as the lungs are able to generate the wealth of peripheral feedback appropriate to a control system dealing with minimizing the energy expenditure of breathing (Vidruk & Dempsey, 1980).

One of the most effective adjustments made at the very onset of exercise is the change from predominately nose breathing to mouth breathing (Vidruk & Dempsey, 1980). This change in pattern minimizes the resistance to airflow and consequently the work of breathing during exercise-induced hyperpnea.

Vidruk & Dempsey (1980) propose that the pattern of exercise-induced ventilation is guided by a precise precept. One possibility being that the control system is genetically programmed. Another is that the control system is learned. Vidruk & Dempsey (1980) knew of no studies which would verify either of these explanations. Vidruk & Dempsey (1980) suggested that if the ventilatory control system has the same capabilities as those controlling movements, then it seems reasonable that it could learn to accomplish a task as efficiently as possible. This suggests that if such a precept could be present in the initiation of a specific pattern of breathing as for other types of movement, then there should be a feedback system capable of providing the pattern generator with a continuous flow of sensory data (Vidruk & Dempsey, 1980).

Respiratory sinus arrhythmia (RSA) is defined as the occurrence of cyclic fluctuations in heart rate that correspond with phase of respiration. Normal individuals are capable of altering their own levels of RSA by effecting particular breathing maneuvers. Rapid, low-tidal-volume breathing will reduce the degree of heart rate variability corresponding to respiratory phase. A slow, deep pattern of breathing, on the other hand, will significantly increase the level of RSA, and a brief pause between inspiration and expiration is likely to further augment it (Angelone & Coulter, 1964; Hirsch & Bishop, 1981: Ross & Steptoe, 1980 as reported in Grossman, 1983).

The relationship between ventilatory pattern and RSA level is apparently the same whether individuals voluntarily alter their breathing pattern or spontaneously manifest ventilatory changes (Hirsch & Bishop, 1981 as reported in Grossman, 1983); implying that variations in breathing pattern continuously moderate cardiac activity at least under conditions of rest (Grossman, 1983). Other studies (Fujihara et al, 1973; Linnarson, 1974; and Szlyk et al, 1981 as reported in Hardin et al, 1987) conclude that exercise is regulated primarily by neural mechanisms in light exercise and by blood stimuli released from exercising muscles during hard work. Endurance athletes appear to develop after training, slower, larger-tidal-volume patterns of breathing during rest and also show heightened levels of RSA (Astrand & Rodahl, 1977; Karpovich & Sinning, 1971; Miyamura, Yamashima, & Honda. 1976 as reported in Grossman, 1983).

The majority of the research in the area of respiration has been done on inactive populations (Grossman, 1983, Clark et al, 1983). Some results, however, may be applicable to a more active population. Research using populations of highly trained athletes is being done. There has been a small body of relevant data from studies in conscious man (Clark et al, 1983). But the data is still limited by the fact that most previous observations were made at resting or only moderately elevated levels of ventilation. Investigators have reported that ventilation rates at high altitude were similar to rates at lower altitudes, but depth of breathing was increased (as reported in Hardin et al, 1987). Others stated that both rate and depth had increased between lower and higher altitudes and hypothesized that athletes would have to relearn breathing rhythms if they were to perform efficiently at a higher altitude.

Clark et al (1983) studied breathing patterns in elite oarsmen during submaximal and maximal exercise. Clark et al (1983) found that marked increases in frequency (f) as exercise workload approaches maximal levels is accomplished by progressive shortening of both T_E and T_I (durations of expiratory and inspiratory phases of the breathing cycle). During this time both T_E and T_I continue to decrease with T_E remaining shorter than T_I. Clark et al (1983) reported that the duration of T_E is determined by the previous T_I in anesthetized cats. This relationship is not always found in conscious man, especially during moderate hyperventilation caused by exercise or hypercapnia.

Current control models of ventilation at rest emphasize interactions between V_T and T_I, and some investigators have concluded that T_E is determined by the previous T_I (Clark et al, 1983). However, duration of T_E both at rest and during exercise appears to be determined at least partly by laryngeal regulation of resistance to expiratory flow. During the more complex states of light to moderate exercise, neural control factors are modulated by chemical effects, and the integrated central and peripheral influences appear to determine a breathing pattern that provides the required V_I with minimal expenditure of work or force (Clark et al, 1983).

Clark et al (1983) explained the prominent decrement in T_E during heavy exercise by the use of active expiration.

Hardin et al (1987) studied the ventilation patterns and stride rates in middle distance runners. The purpose of the study was to investigate the effects of proprioceptive stimuli from muscles and joints as effectors of respiratory rates, and to measure these respiratory rates in athletes while running at competitive paces.

Using four male collegiately skilled middle distance runners Hardin et al (1987) looked at the ratio of running strides to breaths during a 880-yard run. The number of strides taken during each quarter

(220-yards) of the test was very constant for each of the runners, while the frequency of respiration increased as the test progressed. Hardin et al (1987) proposed that the degree of stimulus from the muscle and joint proprioceptive mechanisms was relatively constant. The increased frequency of respiration must have been due to stimulation from other sources such as humoral chemical stimuli.

To support the conclusion that humoral chemical stimuli are involved, Hardin et al (1987) ran the same runners on a treadmill at controlled rates. No blood samples were analyzed to confirm chemical change and depth of breathing was not measured to show changes in respiratory volumes, but there was indicated that a mechanism (probably chemical) overrides the proprioceptive controls of respiration as the severity of exercise increases (Hardin et al, 1987). Hardin et al (1987) proposed that the data seem to support the statement by Astrand and Rodahl (1970), "The efferent impulses from exercising limbs and stimulation from the brain due to increased motor activity must be considered as coordinated activators of respiratory muscles but their motorneurons are subjected to various degrees of inhibition from the respiratory centers depending on the chemical composition of the blood".

It has been found that breathing may be synchronized with locomotion in running mammals due to mechanical constraints (Bramble & Carrier, 1983). Some investigators have observed that breathing frequency is often a submultiple of the stepping rate in treadmill exercise, while others have found no such relationship (Bannister et al, 1954; Hey et al, 1966; Kay et al, 1975 and 1957; Kelman & Watson. 1973; as reported in Clark et al, 1983).

Most of the evidence favoring an intrinsic linkage between locomotion and respiration in mammals has come from physiological experiments on anesthetized, decebrate laboratory animals and from bicycle ergometer tests on humans (Bramble & Carrier, 1983). It has been shown that human subjects may display complete or partial entrainment of respiratory rate to step or pedal frequency during test on treadmills or bicycle ergometers. However, the percentage of subjects exhibiting locomotor-respiratory synchronization in such experiments has varied greatly, and some investigators have found no evidence of entrainment (Bramble & Carrier, 1983, and Clark et al, 1983).

Various biomechanical considerations lead to the simple proposition that locomotion and respiration are not independent phenomena in running mammals (Bramble & Carrier, 1983). This proposition is based on the assumption that locomotion imposes limits on respiratory function and that breathing must therefore be made to fit the locomotor cycle. For example, locomotion and respiration both rely on cyclic movements in the same anatomic system, most specifically the thoracic complex (ribs, sternum, and associated musculature) (Bramble & Carrier, 1983). Also, because the visceral mass is not firmly connected to the body frame it can be expected to shift position within the abdominal cavity. Because visceral motion will be somewhat out of phase with that of the musculoskeletal frame, the abdominal mass potentially constitutes a "visceral piston", the movements of which could influence respiration by altering intra-abdominal and intrathoracic volume (and pressure) (Bramble & Carrier, 1983).

Among modern mammals, humans alone utilize a striding bipedal gait. Because of this unusual locomotor pattern the thoracic complex is no longer subjected to direct impact loading (Bramble & Carrier, 1983).

Bramble & Carrier (1983) studied human runners for locomotor-respiratory coupling (LRC). The subjects included both experienced, conditioned runners and persons having little or no serious running experience. Breathing signals and footfalls were recorded during slow, moderate, and fast running speeds.

Breathing and gait were tightly coupled in the experienced runners. Phase-locked locomotor and respiratory cycles were observed in these individuals for runs up to 1.25 miles (Bramble & Carrier, 1983). In all cases it was evident that breathing was entrained to gait and not the reverse. In the most experienced (marathon) runners, phase locking occurred within the first four or five strides of a run. Less experienced runners required somewhat longer distances before breathing and gait were fully coupled (Bramble & Carrier, 1983). The inexperienced runners typically showed little or no tendency to synchronize gait and respiration.

Bramble & Carrier (1983) found that humans use at least five distinct coupling patterns, with the predominant ratio appearing to be 2:1 (strides per breath). Slower sustained running speeds are frequently accompanied by a ratio of 4:1. As speed increases the ratio decreases. Shifts in coupling ratio occurred quickly and smoothly over just a few strides (Bramble & Carrier, 1983). Other sustained LRC ratios observed in humans running at moderate speed were 3:1, 5:2, and 3:2.

The bulk flow of air to and from the lungs occurs in discrete pulses rather than as smooth biphasic flow (Bramble & Carrier, 1983). Exhalation begins in the floating phase of the locomotor cycle. Most air is expelled in a large initial burst beginning at or very near the impact of the left foot (Bramble & Carrier, 1983). Both exhalation and inhalation are commonly represented by two bursts, with the inhalation bursts being of much lower amplitude than those of exhalation (Bramble & Carrier, 1983). The time spent in exhalation is noticeably longer than that devoted to inhalation.

Bramble & Carrier (1983) found that runners in whom breathing and gait are tightly coupled are "footed"; that is, the beginning and end of a respiratory cycle are associated with the same footfall when even coupling ratios are used (4:1 or 2:1). The result is that the center of gravity is raised higher during push-off by one leg than the other; consequently, body loading is expected to be asymmetric as well (Cavanagh et al, 1977 as reported in Bramble & Carrier, 1983).

For humans, Bramble & Carrier (1983) found that increases in running speed are not attended by changes of gait. The inability of humans to change gait while running implies that their exceptional capacity to alter breathing pattern could to some extent represent an alternative strategy for regulating energetic cost. This variable coupling in humans becomes a kind of pulmonary gearing mechanism within a fixed locomotor program.

Bramble & Carrier (1983) proposed that the data from free-running mammals strongly support the concept of neurogenic control, but do not indicate the relative importance of peripheral as opposed to central mechanisms in such control. The shift of LRC ratio in human runners occurs without any detectable alteration in the motor program. This indicates that other stimuli, probably metabolic, trigger the change of breathing (Bramble & Carrier, 1983).

For years, leading swim coaches have promoted hypoxic training conditions with the intent of producing physiological changes which may enhance swim performance in aerobic and anaerobic events (Bell, 1981). During swimming, an involuntary hypoxia exists due to the rhythmical movements of the arms and the head to breathe. Bell(1981) studied the effects of two breathing patterns (1. breathing every stroke, 2. breathing every other stroke) on selected physiological parameters of male swimmers. Bell(1981) concluded that when breathing only on alternate arm strokes, a swimmer can perform at submaximal speed with lower metabolic cost. Additionally, it is possible that when performing at near maximal speeds in the 200-yard freestyle, a swimmer will incur less fatigue when breathing on alternate arm strokes (Bell, 1981).

Hardin et al (1987) proposed a practical application from the data collected, "...that requiring an athlete to concentrate on rhythmical breathing during endurance events may be warranted, although breathing patterns adjust through several mechanisms that are self-regulatory even at high altitudes. However, the cost of additional breathing (rate and depth) will involve many respiratory muscles and that these muscles, if not conditioned, may become a limiting factor in endurance contests". Martin et al (1984), however, indicate that anaerobic metabolism in maximal exercise may warrant breathing control (reported in Hardin et al, 1987).

The components of this study, respiration and performance are interrelated with the activity of relaxation. It appears that the typical respiratory pattern characteristic of stressful situations is one of rapid rate, altered tidal volume, relative hypocapnia, and predominately thoracic mode. Relaxing enhances abdominal-diaphragmatic breathing thus relieving the stressful situation. A sign of a relaxed state is a change in respiration. Deep breathing with long exhalations contribute to relaxation (Curtis & Detert, 1981). Relaxation is also a function of peak performance. Peak performance is a time when everything comes together exactly right and every movement is fluid, sure, and natural for the athlete (Garfield & Bennett, 1984; Elliott, 1984). This level of performance occurs when the athlete is relaxed and lets his physical skills flow automatically (Garfield & Bennett, 1984). Relaxation is a physiological state that is the opposite of the stress state (Curtis & Detert, 1981). The relaxation response is usually attained by first altering the respiration pattern. For relaxation the respiration pattern is altered by prolonging the exhalation; a feature contained in the breathing pattern used by the present subjects. A study by Haas, Axen, Ehrilchman, & Haas (1980 as reported in Grossman, 1983) found results characterizing the differences between relaxed people and anxious people. Individuals whose habitual breathing patterns were slow and of large tidal volume were found to be confident, emotionally stable, and physically and intellectually active individuals. On the other hand, rapid, low-tidal-volume breathers tended to be passive, dependent, fearful and shy. Differences between groups were significant.

These findings are supported by several studies which clearly indicate that voluntary alterations in breathing pattern can modulate the subjective experience of stressful situations (as reported in Grossman, 1983).

Relaxation has also been reported to decrease oxygen consumption. For a distance runner this means that he will require less oxygen to run the same speed (Elliott, 1984).

Zi (1986) has used the idea of imagery to help people learn to control and to utilize more efficiently their respiration. Zi (1986) feels having an effective breathing system performance in any activity will be enhanced. This study is attempting to investigate the effects of a specific respiration pattern for runners. The runners that are the subjects in this study are to use a respiration pattern that involves inhaling for two (2) strides and exhaling for three (3) strides while performing at maximal and submaximal exertion. This study will investigate the effects of this breathing pattern on the runners performance at two different workloads.

Chapter 3

METHOD

Pilot Study

A pilot study was conducted during the fall quarter of 1986. Five male subjects from the University of Montana Cross Country team participated in mental practice of a specific respiration pattern. The objective was to teach the runners to consciously manipulate their breathing pattern to improve running efficiency. The subjects averaged 6.8 sessions which lasted approximately fifteen minutes each. From the feedback given the researcher throughout the pilot study the present study was developed.

For several reasons, this study was developed from the pilot study. First, because of familiarity with the task the subjects from the previous study were used. The subjects prior experience both physically and mentally with the specific respiration pattern classified the runners as being skilled at the task. Second, the benefits of relaxation and visualization, (e.g., lowered arousal and improved concentration) were reported in the pilot study. Third, the idea that conscious control of respiration may improve running performance and/or efficiency.

This investigation is an extension of a pilot study using the same sample. The investigator worked in conjunction with the running coach at the University of Montana, teaching particular breathing exercises to the runners. The objective was for the runners to gain conscious control of their breathing in a more energy efficient pattern to aid in performance. During the last year the runners (subjects) had been exposed to the breathing pattern via verbal communication from the coach.

PROCEDURE

Subjects

The subjects in this study were six (6) collegiate and post-collegiate distance runners. Four were members of the University of Montana Cross country and track teams, while two were alumnus of those teams. The runners participated on the basis of their involvement from the pilot study. Informed consent was obtained from each subject. (See Appendix A) The runners worked with the investigator in unstructured mental practice sessions for six weeks, rehearsing the controlled respiration pattern. Subjects were instructed to physically practice the respiration pattern while running. Data was collected to assess the subjects characteristics in terms of: age, height, weight, number of years running, number of years running collegiately and post-collegiately, and best time for specific distances (see Appendix B). Physical characteristics of the subjects can be found in Table 1. Each of the subjects were in a transition from a pre-competition program to a competition program of training when the data was gathered in March of 1987.

Apparatus

The performance measurement was done on a Quinton treadmill using an open-circuit spirometry. Measurement of the number of breaths (counted as inhalations), the volume of air ventilated through the lungs, the volume of oxygen used, carbon dioxide volume produced, and

TABLE 1

Characteristics of Subjects

Subject	Age	Height (cm)	Weight (kg)	Best time for 1500m	5000m
1	21	175	63.55	4:20	16:48
2	20	175	66.75		15:30
3	18	177.5	68.45	3:59	
4	20	172.5	58.00	4:02	14:46
5	26	177.5	69.90	4:10	15:22
6	24	180	67.80	3:51	13:56
Means	21.5	176.25	65.74	4:04	15:26

respiratory quotient (RQ) was recorded by a Beckman Metabolic Measurement Apparatus (MMA) for each subject. A nose clip was worn as part of the spirometry apparatus. Figure 1 shows pictures of the Beckman MMA and a subject hooked up to it.

Heart rate was recorded by a Quantum XL Heart Rate Monitor. Figure 2 shows the Quantum XL Heart rate monitor and as it was worn by the subjects.

A Panasonic Video Recorder and Camera was used to videotape the number of strides the runner took in conjunction with his ventilation.

The camera was positioned diagonally off of the subjects right shoulder, at head level, focused in on the face and the spirometry mouthpiece. A 3'x 5' mirror was positioned on the left side of the subject to reflect the legs into the camera. This process provided a split screen image on one video camera and recorder. Figure 3 shows pictures of the lab set up in terms of the video camera and mirror.

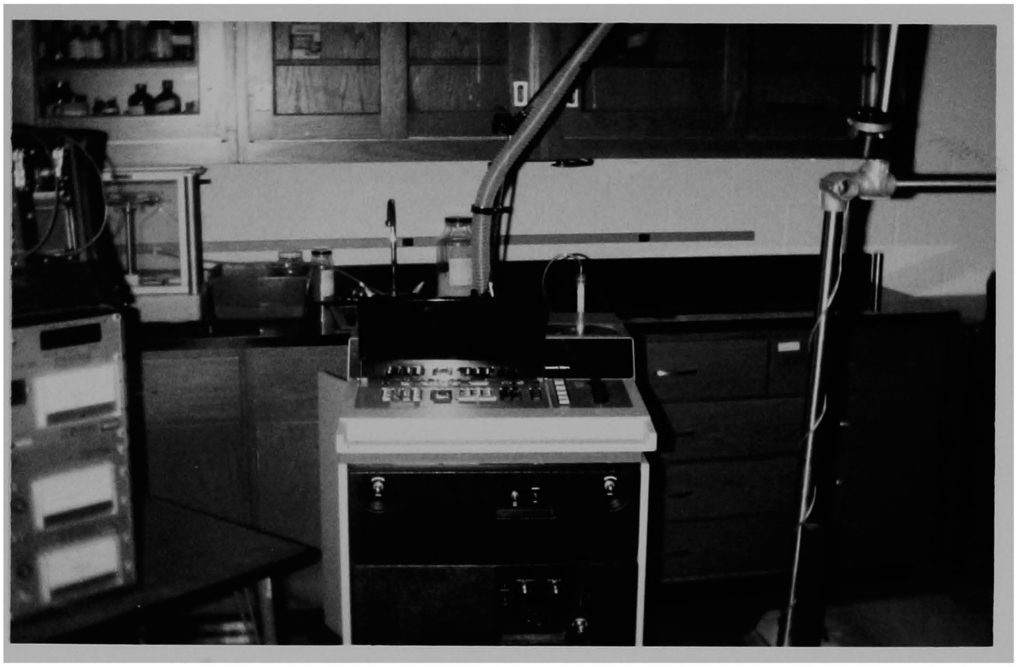
Design

The controlled respiration pattern consisted of inhaling for two (2) strides and exhaling for three (3) strides. The main criterion was the occurrence of a longer exhalation phase than inhalation phase in terms of the number of strides taken. This controlled respiration pattern was compared to the runners uncontrolled normal respiration pattern.

Individuals have reported the use of different respiration patterns (i.e., 2 strides inhale-3 strides exhale, 2-5, 3-4) for enhanced performance (Plunkett, 1986), but no empirical laboratory studies could be found by the investigator. The two procedures are; group A = test 1 & 3 running and test 2 & 4 focusing on the exhalation, group B = test 1 & 3 focusing on the exhalation and test 2 & 4 running. The subjects were randomly placed into the two procedure groups. The performance task chosen was a specific controlled respiration pattern used during running, at a maximal and submaximal aerobic effort. Half of the subjects (group A) were instructed to focus on the controlled breathing pattern (exhalation) for the first and third tests while the other subjects (group B) ran normally for the first and third tests. For the second and fourth tests group A was

Figure 1.

Pictures of the Beckman Metabolic Measurement Apparatus and a subject hooked to the apparatus.



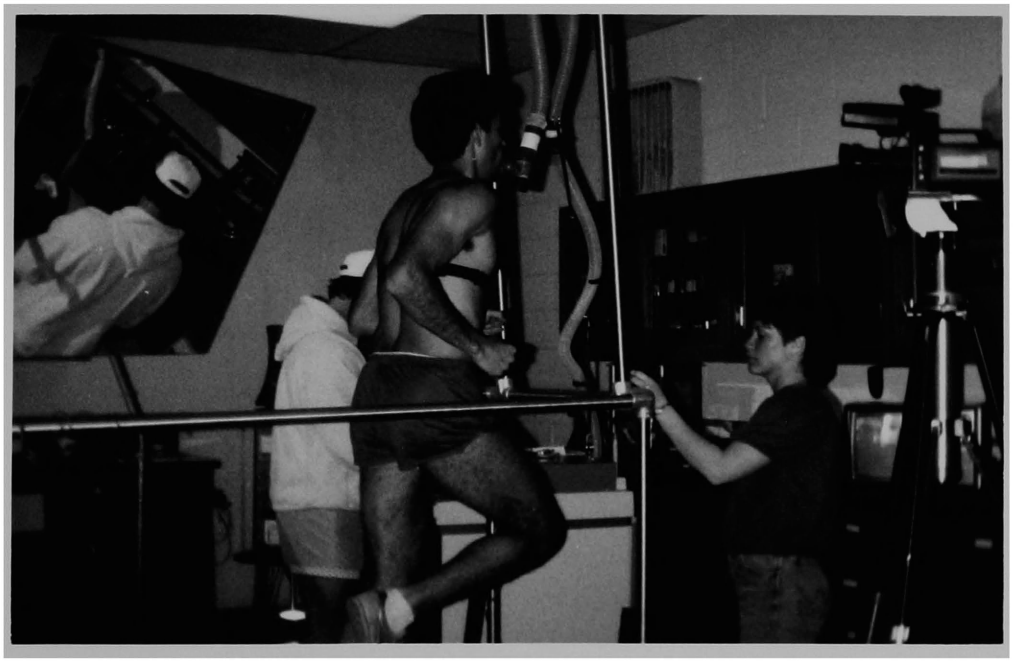


Figure 2.

The Quantum XL Heart Rate monitor as worn by the subjects.

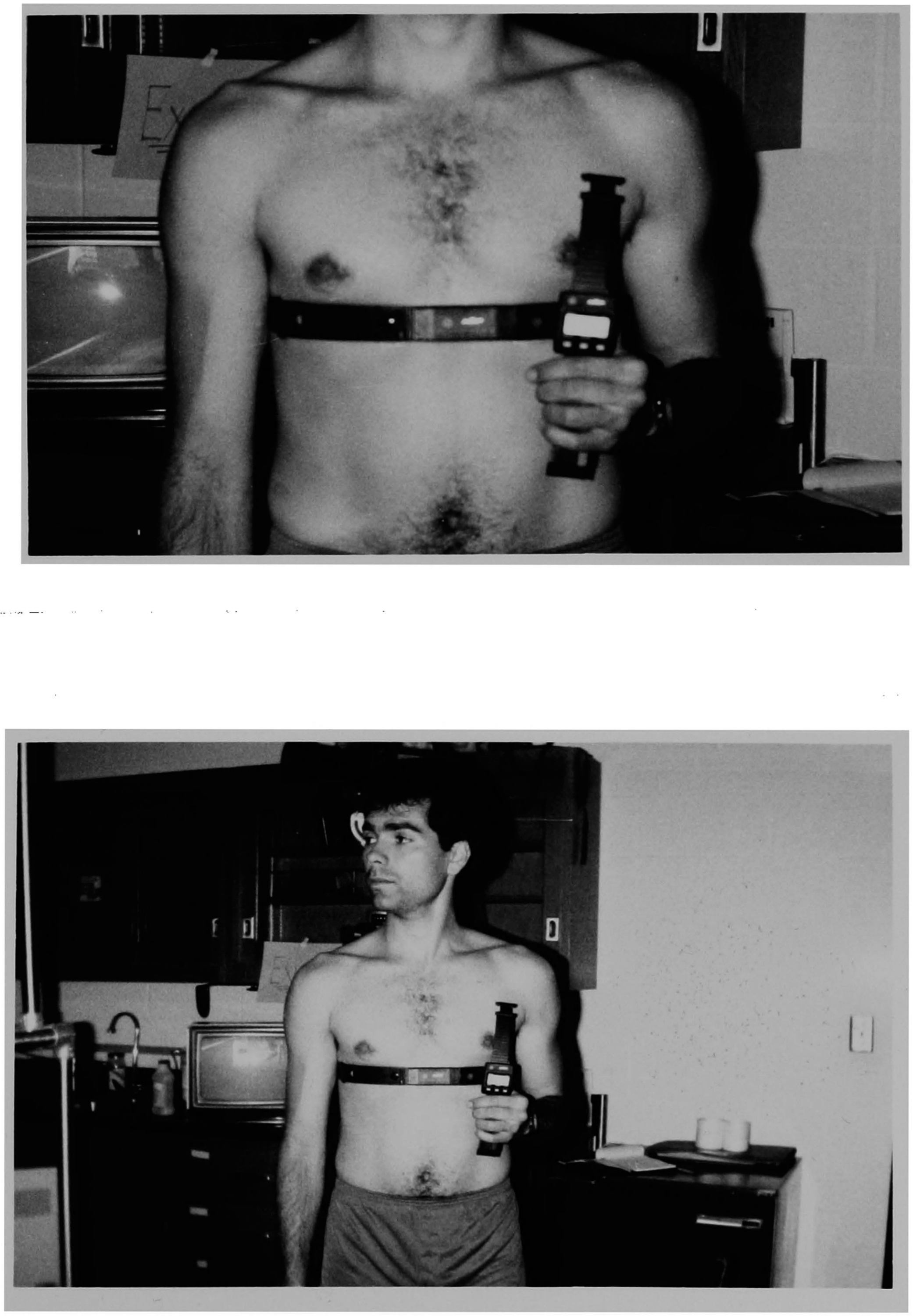


Figure 3.

Lab set up of the video camera and mirror.

instructed to run normally while group B was instructed to focus on the exhalation for the second and fourth tests.

Prior to the testing day the subjects attended an acclimatization period of running on the treadmill with a mouthpiece and nose clip attached.

The testing began with a five-minute warm-up run for the subject on the treadmill. The subject was then hooked up to the ECG apparatus and the spirometry mouthpiece and nose clip. The testing period was conducted from a running start. The treadmill was started at 3 miles per hour (mph) with the subject on it. Every five seconds the speed was increased 1 mph up to the task pace; 12.75 mph for tests 1 & 2 or 9.75 mph for tests 3 & 4. Fifteen seconds after the task speed was achieved the 3-minute data collection period began. Every 15 seconds heart rate (HR) was recorded and every 30 seconds ventilation, oxygen consumption, respiratory quotient, and the number of breaths was recorded (see Appendix C & D). Video taping was conducted over the entire procedure. The protocol listed above was repeated for all four tests.

DATA ANALYSIS

The physiological performance results were analyzed by use of a t-test comparing the controlled test to the uncontrolled test at both intensity levels. Each 30 second segment of the tests were compared as well as the mean score for each test. Significance was determined to occur at the .05 alpha level. The videos were analyzed for the ratio of strides to breaths for comparison of the number of strides taken during exhalation and the number of strides taken during inhalation.

The videos were analyzed in slow-motion speed by the investigator and an assistant counting the number of inhalations and exhalations in comparison to the number of strides. The total number of breaths taken for each 30 second segment were also recorded.

CHAPTER 4

ANALYSIS OF RESULTS

This chapter presents the data obtained in this study and statistical analysis of the data.

The controlled respiration pattern on the parameters measured was compared to the uncontrolled respiration pattern, using a two-tailed t test for the mean difference at the .05 alpha level of significance. Test means, the mean differences, and the statistical significance of differences for the ten variables measured across the individual time segments and the sum of those time segments are presented in tables 2 through 11 and 12 through 21, respectively.

Moderate intensity tests

Five of the subjects completed both 4-minute tests, while the sixth subject was stopped after two minutes of his second test. This subject did not complete either of the high intensity tests. No overall differences between the controlled breathing test and the uncontrolled test were shown with the exception of one significant 30-second time segment. Table 10 indicates the number of strides taken per 30 second segment for all tests. During the fifth segment (120-150s) the number of strides taken during the controlled breathing test were significantly greater than those taken during the uncontrolled test (89 strides to 83 strides respectively, $p < 0.006$).

During the seventh segment (180-210s) the production of carbon dioxide (VCO_2 in ml/min) was greater during the controlled breathing test compared to the uncontrolled test (2,753.0 L to 2,595.4 L

TABLE 2

Total Ventilation (ml/min)

Means and significance level of each 30 second (s) segment for the **Moderate** intensity tests.

Time		Means		Mean Difference	Significance **
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=6	65,520.50	71,635.00	-6,114.50	0.161
30-60s	n=6	78,847.00	82,708.50	-3,861.50	0.475
60-90s	n=6	81,629.33	84,886.66	-3,257.33	0.403
90-120s	n=6	85,417.83	83,872.16	1,545.66	0.745
120-150s	n=6	84,209.33	82,839.50	1,369.83	0.710
150-180s	n=5	80,014.20	83,409.80	-3,395.60	0.398
180-210s	n=5	82,852.80	83,261.60	- 408.80	0.909
210-240s	n=5	79,601.40	83,503.40	-3,902.00	0.310

Means and significance level for each 30 second (s) segment for the **High** intensity tests.

Time		Means		Mean Difference	Significance **
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=5	86,508.20	93,279.20	-6,771.00	0.210
30-60s	n=5	105,384.80	110,003.40	-4,618.60	0.306
60-90s	n=5	113,372.80	117,806.00	-4,433.20	0.307
90-120s	n=5	119,904.60	124,139.20	-4,234.60	0.360
120-150s	n=3	117,526.33	116,288.66	1,237.66	0.867
150-180s	n=3	121,112.33	121,580.33	- 468.00	0.960

TABLE 3

Oxygen Uptake (VO_2) (ml/min/kg)

Means and significance level of each 30 second (s) segment for the Moderate intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=6	32.96	34.60	-1.63	0.610
30-60s	n=6	43.56	43.19	0.35	0.735
60-90s	n=6	43.86	44.16	-0.30	0.802
90-120s	n=6	45.78	44.41	1.36	0.346
120-150s	n=6	44.43	43.45	0.98	0.514
150-180s	n=6	46.25	44.70	1.55	0.069
180-210s	n=5	46.06	43.36	2.70	0.021 **
210-240s	n=5	45.26	44.00	1.26	0.204

Means and significance level of each 30 second (s) segment for the High intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance
0-30s	n=5	42.38	47.86	-5.48	0.012 **
30-60s	n=5	52.48	54.04	-1.56	0.408
60-90s	n=5	53.92	55.92	-2.00	0.304
90-120s	n=5	57.10	57.64	-0.54	0.629
120-150s	n=3	54.06	57.83	-3.76	0.263
150-180s	n=3	55.46	60.80	-5.33	0.132

TABLE 4

VCO₂ (volume of Carbon Dioxide)

Means and significance level of each 30 second (s) segment for the **Moderate** intensity tests.

Time		Means		Mean Difference	Significance **
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=6	1,836.33	1,989.50	-153.16	0.250
30-60s	n=6	2,412.16	2,519.83	-107.66	0.289
60-90s	n=6	2,544.33	2,628.66	- 84.33	0.297
90-120s	n=6	2,745.33	2,613.50	131.83	0.260
120-150s	n=6	2,715.16	2,620.16	95.00	0.184
150-180s	n=5	2,691.80	2,603.80	88.00	0.249
180-210s	n=5	2,753.00	2,595.40	157.60	0.015 **
210-240s	n=5	2,690.80	2,620.60	70.20	0.229

Means and significance level for each 30 second (s) segment for the **High** intensity tests.

Time		Means		Means Difference	Significance
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=5	2,337.20	2,396.20	- 59.00	0.753
30-60s	n=5	3,347.00	3,219.40	127.60	0.648
60-90s	n=5	3,799.80	3,613.60	186.20	0.510
90-120s	n=5	4,162.00	3,961.00	201.00	0.317
120-150s	n=3	3,736.66	3,812.33	- 75.66	0.805
150-180s	n=3	3,835.33	4,078.33	-243.00	0.394

TABLE 5

Respiratory Quotient (RQ)

Means and significance level of each 30 second (s) segment for the **Moderate** intensity tests.

Time		Means Controlled Breathing	Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=6	0.85	0.88	-0.03	0.562
30-60s	n=6	0.84	0.87	-0.02	0.170
60-90s	n=6	0.88	0.90	-0.01	0.159
90-120s	n=6	0.91	0.90	0.00	0.606
120-150s	n=6	0.92	0.89	0.03	0.070
150-180s	n=5	0.90	0.90	-0.00	0.838
180-210s	n=5	0.91	0.91	0.00	1.000
210-240s	n=5	0.90	0.90	0.00	1.000

Means and significance level of each 30 second (s) segment for the **High** intensity tests.

Time		Means Controlled Breathing	Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=5	0.84	0.77	0.06	0.220
30-60s	n=5	0.97	0.91	0.05	0.369
60-90s	n=5	1.07	1.00	0.07	0.179
90-120s	n=5	1.11	1.05	0.05	0.178
120-150s	n=3	1.10	1.05	0.04	0.302
150-180s	n=3	1.10	1.07	0.03	0.374

TABLE 6

Percentage of Carbon Dioxide (CO_2) Expired

Means and significance level of each 30 second (s) segment of the Moderate intensity tests.

Time		Means		Mean Difference	Significance **
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=6	3.92	3.85	0.071	0.277
30-60s	n=6	4.28	4.21	0.075	0.650
60-90s	n=6	4.38	4.29	0.091	0.608
90-120s	n=6	4.52	4.29	0.228	0.338
120-150s	n=6	4.52	4.37	0.148	0.465
150-180s	n=5	4.72	4.34	0.382	0.112
180-210s	n=5	4.69	4.32	0.368	0.132
210-240s	n=5	4.76	4.36	0.408	0.057

Means and significance level of each 30 second (s) segment for the High intensity tests.

Time		Means		Mean Difference	Significance **
		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=5	3.79	3.54	0.244	0.585
30-60s	n=5	4.46	4.03	0.428	0.293
60-90s	n=5	4.67	4.26	0.410	0.233
90-120s	n=5	4.84	4.39	0.452	0.189
120-150s	n=3	4.55	4.58	-0.036	0.898
150-180s	n=3	4.48	4.65	-0.163	0.498

TABLE 7

Percentage of Oxygen used (O_2)

Means and significance level of each 30 second (s) segment of the **Moderate** intensity tests.

		Means		Mean Difference	Significance **
Time		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=6	16.41	16.60	-0.190	0.466
30-60s	n=6	15.95	16.22	-0.273	0.362
60-90s	n=6	16.05	16.26	-0.211	0.422
90-120s	n=6	16.02	16.26	-0.241	0.328
120-150s	n=6	16.10	16.15	-0.055	0.813
150-180s	n=5	15.80	16.24	-0.446	0.111
180-210s	n=5	15.89	16.30	-0.408	0.174
210-240s	n=5	15.78	16.23	-0.454	0.076

Means and significance level of each 30 second (s) segment of the **High** intensity tests.

		Means		Mean Difference	Significance **
Time		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=5	16.53	16.54	-0.004	0.991
30-60s	n=5	16.32	16.60	-0.278	0.396
60-90s	n=5	16.48	16.67	-0.192	0.453
90-120s	n=5	16.46	16.70	-0.240	0.289
120-150s	n=3	16.66	16.48	0.180	0.365
150-180s	n=3	16.75	16.50	0.250	0.244

TABLE 8

Heart Rate (beats per minute)

Means and significance level of each 30 second (s) segment for the Moderate intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=6	149.8	151.0	-1.16	0.592
30-60s	n=6	154.6	155.3	-0.66	0.618
60-90s	n=6	156.8	156.8	0.00	1.000
90-120s	n=6	158.5	159.1	-0.66	0.530
120-150s	n=5	155.8	157.0	-1.20	0.529
150-180s	n=5	157.4	158.0	-0.60	0.501
180-210s	n=5	159.4	159.4	0.00	1.000
210-240s	n=5	159.4	161.2	-1.80	0.195

Means and significance level of each 30 second (s) segment for the High intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=5	164.2	168.6	-4.40	0.108
30-60s	n=5	171.6	172.2	-0.60	0.741
60-90s	n=5	173.8	175.6	-1.80	0.346
90-120s	n=5	176.4	178.0	-1.60	0.195
120-150s	n=3	174.0	178.3	-4.33	0.096
150-180s	n=3	177.6	179.0	-1.33	0.529

TABLE 9

Number of Strides taken during the test

Means and significance level of each 30 second (s) segment of the **Moderate** intensity tests.

		Means		Mean Difference	Significance **
Time		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=6	92.83	90.00	2.833	0.478
30-60s	n=6	89.16	88.33	0.833	0.860
60-90s	n=6	90.00	89.66	0.333	0.910
90-120s	n=6	89.66	92.00	-2.333	0.371
120-150s	n=6	89.50	83.33	6.166	0.006 **
150-180s	n=5	88.60	90.20	-1.600	0.516
180-210s	n=5	92.80	91.40	1.400	0.685
210-240s	n=5	90.00	92.00	-0.200	0.974

Means and significance level of each 30 second (s) segment of the **High** intensity tests.

		Means		Mean Difference	Significance **
Time		Controlled Breathing	Uncontrolled Breathing		
0-30s	n=4	99.25	98.25	1.000	0.784
30-60s	n=4	99.50	96.75	2.750	0.436
60-90s	n=4	94.25	97.25	-3.000	0.601
90-120s	n=4	96.50	93.25	3.250	0.051
120-150s	n=2	98.00	94.50	3.500	0.395
150-180s	n=2	94.00	98.50	-4.500	0.421

TABLE 10

Number of Breaths taken during the test

Means and significance level of each 30 second (s) segment of the **Moderate** intensity tests.

Time		Means: Controlled Breathing	Means: Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=6	16.66	16.16	0.500	0.844
30-60s	n=6	17.83	17.67	0.166	0.952
60-90s	n=6	18.83	17.66	1.166	0.675
90-120s	n=6	19.00	17.83	1.166	0.665
120-150s	n=6	19.33	16.00	3.333	0.252
150-180s	n=5	17.40	18.00	-0.600	0.831
180-210s	n=5	19.00	17.80	1.200	0.685
210-240s	n=5	17.80	18.00	-0.200	0.949

Means and significance level of each 30 second (s) segment of the **High** intensity tests.

Time		Means: Controlled Breathing	Means: Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=4	18.25	19.25	-1.000	0.745
30-60s	n=4	19.25	19.75	-0.500	0.869
60-90s	n=4	20.25	21.00	-0.750	0.798
90-120s	n=4	21.00	21.50	-0.500	0.848
120-150s	n=2	19.00	17.50	1.500	0.742
150-180s	n=2	20.00	19.00	1.000	0.844

TABLE 11

The ratio of number of strides per breaths for the test

Means and significance level of each 30 second (s) segment of the **Moderate** intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=6	6.34	5.83	0.511	0.696
30-60s	n=6	5.53	5.18	0.353	0.747
60-90s	n=6	5.30	5.27	0.030	0.971
90-120s	n=6	5.28	5.39	-0.113	0.884
120-150s	n=6	5.25	5.41	-0.156	0.854
150-180s	n=5	5.72	5.25	0.466	0.583
180-210s	n=5	5.42	5.32	0.102	0.902
210-240s	n=5	5.62	5.34	0.284	0.637

Means and significance level of each 30 second (s) segment of the **High** intensity tests.

Time		Means Controlled Breathing	 Uncontrolled Breathing	Mean Difference	Significance **
0-30s	n=4	6.06	5.29	0.767	0.445
30-60s	n=4	5.55	5.01	0.547	0.483
60-90s	n=4	5.04	4.67	0.362	0.613
90-120s	n=4	4.82	4.46	0.365	0.517
120-150s	n=2	5.67	5.46	0.205	0.889
150-180s	n=2	5.00	5.20	-0.205	0.839

respectively, $p < 0.015$). Table 4 displays the volume of CO_2 for all tests.

Tables 6 & 7 show the percentage of CO_2 expired and the percentage of O_2 used for all tests, respectively. During the eighth, and final, segment (210-240s) the percentage of CO_2 expired was greater during the controlled breathing test (4.76 to 4.36), while at the same time the percentage of O_2 used was greater during the uncontrolled test (16.23 to 15.78).

During the fifth segment (120-150s) respiratory quotient (the ratio of $VCO_2 \div VO_2$) was greater during the controlled breathing test than during the uncontrolled test (.92 to .89 respectively). Table 5 describes the data for the respiratory quotient.

Table 3 explains the variable of oxygen uptake. During the seventh segment (180-210s) oxygen uptake (VO_2 [ml/min/kg]) was significantly greater during the controlled respiration test compared to the uncontrolled test (46.06 ml/min/kg to 43.36 ml/min/kg, $p < 0.021$).

<u>High intensity tests</u>

Three of the subjects completed both 3-minute tests, while two subjects completed 2 minutes of the second test. For one subject the test not completed was the uncontrolled test and the other subject was doing the controlled breathing test when he could no longer continue and withdrew.

No overall differences between the controlled breathing test and the uncontrolled test were shown. Three time segments indicated differences in test variable means that were statistically significant.

The first segment (0-30s) showed oxygen uptake (VO_2 [ml/min/kg]) to be significantly greater during the uncontrolled test compared to the controlled breathing test (47.8 ml/min/kg to 42.3 ml/min/kg, $p < 0.012$). The values collected for VO_2 can be found in table 3.

The number of strides taken during the fourth segment (90-120s) was greater during the controlled respiration test (96.5 strides to 93.25 strides) than the uncontrolled test,but this was not statistically significant. Table 9 shows the strides taken.

Table 8 describes the heart rate values for each segment. No significant differences were found.

The overall moderate intensity controlled breathing test compared to the uncontrolled test for total ventilation (V_E ml/min) indicated no significant differences between means, even though the uncontrolled test averaged a greater volume (ml/min) (67,656.97 L to 65,937.33 L, $p < 0.598$). The same pattern occurred in the high intensity tests. The uncontrolled test had a greater volume (89,045.56 L to 85,034.08 L, $p < 0.239$) than did the controlled breathing test. The values collected for V_E can be found in table 12.

The oxygen uptake (VO_2 [ml/min/kg]) was slightly greater during the controlled breathing test than during the uncontrolled test (42.8 ml/min/kg to 42.5 ml/min/kg, $p < 0.787$) for the moderate intensity tests. During the high intensity runs the oxygen uptake in the uncontrolled test was significantly greater than the controlled breathing test (43.0 ml/min/kg to 41.1 ml/min/kg, $p < 0.099$). Table 13 reflects oxygen uptake.

Table 14 illustrates the volume of CO_2 used by the subjects. During the moderate intensity tests the VCO_2 (ml/min) was slightly greater during the uncontrolled test than the controlled breathing test (2,061.94 L to 2,042.22 L, $p < 0.757$). The high intensity tests showed a larger mean difference and this time in favor of the controlled breathing test (2,729.20 L to 2,638.04 L, $p < 0.621$).

The respiratory quotient was not significantly different for either of the test intensities. The moderate intensity tests had R.Q.'s of .73 for the controlled breathing test and .74 for the uncontrolled test ($p < 0.584$). The high intensity tests had a greater difference with the controlled breathing test R.Q. of .80 and the uncontrolled test, .75 ($p < 0.227$). Table 15 illustrates the measures collected for RQ.

Heart rate was not significantly different among treatments during the moderate intensity or high intensity tests. The mean heart rate during the moderate intensity runs was 103.3 beats per minute (bpm) for the controlled breathing and 103.7 (bpm) for the uncontrolled ($p < 0.672$). For the high intensity runs the controlled breathing test had a mean heart rate of 137.0 compared to 138.1 for the uncontrolled test ($p < 0.311$). Table 18 indicates the heart rate.

Table 17 shows the percentage of O_2 used. The percentage of oxygen (O_2) used showed similar scores for all tests. The moderate intensity was 13.42 for controlled breathing and 13.58 for uncontrolled ($p < 0.322$). The high intensity scores were 13.16 for controlled breathing and 13.30 for uncontrolled ($p < 0.480$).

TABLE 12

Total Ventilation

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	65,937.33 Liters	-1719.63	0.598
Uncontrolled Breathing	67,656.97 Liters		

Means and significance level of the High intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	85,034.08 Liters	-4011.48	0.239
Uncontrolled Breathing	89,045.56 Liters		

TABLE 13

Oxygen Uptake (VO_2)

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	42.81 ml/min/kg	0.2694	0.787
Uncontrolled Breathing	42.54 ml/min/kg		

Means and significance level of the High intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	41.17 ml/min/kg	-1.9160	0.099
Uncontrolled Breathing	43.09 ml/min/kg		

TABLE 14

VCO_2 (volume of Carbon dioxide)

Means and significance level of the **Moderate** intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	2,042.22 Liters	-19.722	0.757
Uncontrolled Breathing	2,061.94 Liters		

Means and significance level of the **High** intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	2,729.20 Liters	91.160	0.621
Uncontrolled Breathing	2,638.04 Liters		

TABLE 15

Respiratory Quotient (RQ) $CO_2 \div O_2$

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean R.Q.	Mean Difference	Significance **
Controlled Breathing	0.73		
		-0.0058	0.584
Uncontrolled Breathing	0.74		

Means and significance level of the High intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean R.Q.	Mean Difference	Significance **
Controlled Breathing	0.80		
		0.0492	0.227
Uncontrolled Breathing	0.75		

The percentage of carbon dioxide (CO_2) expired showed similar means for all tests also. The moderate intensity test mean for the controlled breathing was 3.6 compared to 3.5 for the uncontrolled test ($p < 0.398$). During the high intensity tests the controlled breathing was 3.5 compared to 3.2 for the uncontrolled ($p < 0.301$). The percentage of CO_2 is illustrated in table 16.

Table 19 shows the number of strides taken during each test. The differences in the number of strides taken by the runners during each test were not statistically significant. For both intensities the mean difference was 1.00 to 1.30 (strides) greater for the controlled respiration tests than the uncontrolled tests.

There was no statistically significant difference in the number of breaths taken during the tests. Table 20 indicates the number of breaths taken during each test. The moderate intensity tests showed the controlled respiration pattern having more breaths, while the high intensity tests indicated that the controlled breathing test had a larger number of breaths.

The ratio of strides and breaths as in table 21, showed no significant difference between treatments. For both the high and moderate intensity tests the controlled breathing pattern had a larger ratio of strides/breath. Table 22 describes the ratio of strides to breaths for each subject during each 30 second segment of each test.

TABLE 16

Percentage of Carbon Dioxide Expired (CO_2)

Means and significance level of the **Moderate** intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	3.6064 %		
		0.1025	0.398
Uncontrolled Breathing	3.5039 %		

Means and significance level of the **High** intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	3.5552 %		
		0.3068	0.301
Uncontrolled Breathing	3.2484 %		

TABLE 17

Percentage of Oxygen used (O_2)

Means and significance level of the **Moderate** intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	13.42 %		
		-0.1619	0.322
Uncontrolled Breathing	13.58 %		

Means and significance level of the **High** intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	13.16 %		
		-0.1428	0.480
Uncontrolled Breathing	13.30 %		

TABLE 18

Heart Rate

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-120s of 240s)	Mean beats/min	Mean Difference	Significance **
Controlled Breathing	103.305 bpm		
		-0.4167	0.672
Uncontrolled Breathing	103.722 bpm		

Means and significance level of the High intensity tests.
Subjects = 5

Test (0-120s of 180s)	Mean beats/min	Mean Difference	Significance **
Controlled Breathing	137.200 bpm		
		-1.6800	0.138
Uncontrolled Breathing	138.880 bpm		

TABLE 19

Number of Strides taken during the test

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean strides/30s	Mean Difference	Significance **
Controlled Breathing	75.19	1.3056	0.510
Uncontrolled Breathing	73.88		

Means and significance level of the High intensity tests.
Subjects = 4

Test (0-120s of 180s)	Mean strides/30s	Mean Difference	Significance **
Controlled Breathing	97.37	1.0000	0.642
Uncontrolled Breathing	96.37		

TABLE 20

Number of Breaths taken during the test

Means and significance level of the **Moderate** intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean breaths/30s	Mean Difference	Significance **
Controlled Breathing	15.27		
		1.0556	0.629
Uncontrolled Breathing	14.22		

Means and significance level of the **High** intensity tests.
Subjects = 4

Test (0-120s of 180s)	Mean breaths/30s	Mean Difference	Significance **
Controlled Breathing	19.68		
		-0.6875	0.794
Uncontrolled Breathing	20.37		

TABLE 21

The ratio of number of strides per breaths for the test

Means and significance level of the Moderate intensity tests.
Subjects = 6

Test (0-150s of 240s)	Mean	Mean Difference	Significance **
Controlled Breathing	4.62 strides/breaths/30s		
		0.1042	0.894
Uncontrolled Breathing	4.51 strides/breaths/30s		

Means and significance level of the High intensity tests.
Subjects = 4

Test (0-120s of 180s)	Mean	Mean Difference	Significance **
Controlled Breathing	5.37 strides/breaths/30s		
		0.5106	0.469
Uncontrolled Breathing	4.86 strides/breaths/30s		

TABLE 22

Data from all variables for all four tests

Test MODERATE	Ventilation V_E ml/min	Oxygen Uptake VO_2 ml/min/kg	Carbon Dioxide CO_2 ml/min	Respiratory Quotient RQ	$\%CO_2$	$\%O_2$	Heart Rate beats/min	Strides	Breaths	Ratio Strides/ Breaths
Controlled Breathing	65,937.33	42.81	2,042.22	0.73	3.6064	13.42	103.305	75.19	15.27	4.62
Uncontrolled Breathing	67,656.97	42.54	2,061.94	0.74	3.5039	13.58	103.722	73.88	14.22	4.51
Mean Difference	-1,719.63	0.2694	-19.722	0.0058	0.1025	-0.1619	-0.4167	1.3056	1.0556	0.1042
Significance	0.598	0.787	0.757	0.584	0.398	0.322	0.672	0.510	0.629	0.894
Test HIGH										
Controlled Breathing	85,034.08	41.17	2,729.20	0.80	3.5552	13.16	137.200	97.37	19.68	5.37
Uncontrolled Breathing	89,045.56	43.09	2,638.04	0.75	3.2484	13.30	138.880	96.37	20.37	4.86
Mean Difference	-4,011.48	-1.9160	91.160	0.0492	0.3068	-0.1428	-1.6800	1.0000	-0.6875	0.5106
Significance	0.239	0.099	0.621	0.227	0.301	0.480	0.138	0.642	0.794	0.469

CHAPTER 5

DISCUSSION, SUMMARY, AND RECOMMENDATIONS

DISCUSSION

The results of the moderate intensity tests and the high intensity tests revealed no statistically significant differences between the controlled breathing pattern and the uncontrolled breathing pattern. It would seem from the data gathered in this study that the controlled breathing pattern is not superior to a runners normal uncontrolled pattern of breathing.

Very little literature is available regarding the effects of consciously controlling respiration during physical activity, e.g. moderate and/or high intensity running(Bell, 1981; Sorbini, et al, 1981; Grossman, 1983). Studies that have attempted to measure a subjects breathing pattern in relation to another pattern during exercise have not compared the efficiency of one pattern to another.

In this study it was hypothesized that the acquisition of the controlled respiration pattern would not effect the energy cost of running. This appeared to be true. Statistically there was no difference in the breathing parameters measured between the controlled breathing pattern and the uncontrolled pattern. There was no significant difference in the total ventilation between either pattern for either test intensities. In both running intensities the uncontrolled pattern had larger ventilation values than the controlled breathing pattern. This is in contrast to the results reported by Jackson (1986) with a trained cyclist. The data obtained in this study may indicate that the controlled breathing pattern may be less efficient than the uncontrolled pattern.

An important measure of efficiency is a persons ability to utilize oxygen. Oxygen uptake was not significant between the treatments in this study, but for the first two minutes of the high intensity test the oxygen uptake for the uncontrolled pattern was greater than in the controlled breathing pattern ($p < 0.099$). For the moderate intensity test the controlled breathing pattern had a slightly larger oxygen uptake value (42.81 L) than the uncontrolled pattern (42.54 L).

Conversely, the respiratory quotient was slightly larger during the high intensity test for the controlled breathing pattern (0.80 to 0.75) than the moderate intensity tests (0.73 to 0.74).

The volume of carbon dioxide produced in the test reflected the same pattern as the Respiratory Quotient. The high intensity test controlled breathing showed a larger volume (2,729.20 L) than the uncontrolled test (2,638.04 L), while the moderate intensity test was the reverse; the controlled breathing was 2,042.22 to the uncontrolled 2,061.94.

The third breathing parameter related to CO_2 production was the percentage of CO_2 expired. For both test intensities the controlled breathing pattern expired more CO_2 than the uncontrolled pattern. Expiring more CO_2 would be expected because of the nature of the controlled respiration pattern. The differences in the two breathing patterns was the length of exhalation. Research has shown that a longer exhalation phase may be beneficial for an athlete when competing (Grossman, 1983). Bell demonstrated with swimmers that a decreased rate of breathing (only on alternate arm strokes) can lower the metabolic cost for the athlete (1981).

In this study the percentage of CO_2 expired was larger during the controlled breathing tests, the percentage of O_2 used was larger during the uncontrolled tests. This would be indicative of a larger VO_2 measure, also. The controlled breathing pattern was possibly promoting a hypoxic state as Bell stated (1981).

Heart rate was greater in the uncontrolled tests at both intensities, although the difference was not statistically significant. An increase in the exhalation phase has been shown to correlate to a decreased heart rate in non-athletic populations (Grossman, 1983). It appears that the controlled breathing pattern was used as instructed which may have resulted in a lower heart rate.

The data show that the breathing patterns measured are inconsistent and do not show one to be superior to the other. This may be due to the fact that breathing patterns adjust through several mechanisms that are self-regulatory (Hardin,1987; Vidruk & Dempsey, 1980).

For a given exercise-induced ventilatory demand (exercise intensity) the breathing pattern favored is the one least costly in terms of energy expenditure (Vidruk & Dempsey, 1980). The exercise stimulus may override any attempt to consciously control breathing especially during high intensity efforts, and employ that breathing pattern which is most efficient for the individual.

The number of strides and the number of breaths taken during the test and the ratio between the two showed no statistically significant changes. The subjects ran on a treadmill, so the number of strides taken would be expected to remain constant across the tests. This was shown to be true for the overall tests. For the individual time segments this was not true. The fifth segment (120-150s) of the moderate intensity test the number of strides taken during the controlled test was greater than the uncontrolled test ($p < 0.006$).

The number of breaths taken for the test should have been different between tests if the subjects were using the controlled breathing pattern. With a longer exhalation the amount of time per breath cycle increases which reduces the total number of breaths required for a given work load. This was not the case in this study. During the moderate intensity test the controlled breathing pattern had a larger number of breaths (15.27) taken than the uncontrolled pattern (14.22). During the high intensity test the controlled breathing pattern had a slightly lower number of breaths (19.68) than the uncontrolled pattern (20.37).

The subjects were taught the controlled breathing pattern in relation to the number of strides taken. The pattern was three strides per exhalation and two strides per inhalation for a ratio of five strides per breath cycle (5:1). Bramble & Carrier found the odd stride per breath cycle resulted in less load force for one leg/side of the body, thus less trauma-injury to a side (1983). There was no statistical significance between the strides:breaths between the different tests. During the moderate intensity tests the controlled breathing pattern showed a ratio of 4.62(strides):1(breath) to 4.51(strides):1(breaths) for the uncontrolled test. The high intensity tests had a similar pattern though larger ratios: 5.37(strides):1(breaths) (controlled) to 4.68(strides):1(breaths) (uncontrolled). The moderate intensity test ratios agreed with Bramble & Carrier (1983), who found slower sustained running speeds to exhibit a 4:1 ratio of strides to breaths. The high intensity tests seem to contradict Bramble & Carrier in that an increase in speed did not cause a decrease in the ratio (1983).

One subject, RAH, demonstrated Bramble & Carriers (1983) findings and, in terms of the study requirements, the controlled breathing pattern. RAH had approximately a 4:1 pattern during both of his uncontrolled tests and a 5:1 pattern during his controlled breathing tests.

The results of this study indicate no statistically significant differences in the two breathing patterns. The normal uncontrolled breathing pattern of the individuals may be the most efficient, although the controlled breathing pattern did not appear to be a hindrance to the subjects. Further investigation into a controlled respiration pattern versus an individuals' normal uncontrolled respiration pattern may still be warranted.

RECOMMENDATIONS

Based on the results of this study, the following recommendations for further study are proposed:

1. Further research is necessary involving a larger number of subjects.

2. The time period for teaching the controlled respiration pattern should be held closer to the testing period.

3. The length of the tests should be increased to provide better baseline readings and the amount of rest between each test should be increased.

SUMMARY

This study investigated the effects of a controlled respiration pattern on the running performance and ventilation parameters of skilled distance runners.

A pilot study was conducted in which the six male subjects practiced the controlled respiration pattern.

The subjects completed four treadmill tests; two each at 9:75 miles per hour (6:09 minute mile pace) and 12.75 mph (4:42 minute mile pace) using the controlled pattern for one test and uncontrolled (natural) breathing pattern for the other test. Breathing parameters were; total ventilation, oxygen uptake, volume of carbon dioxide, respiratory quotient, heart rate, percentage of oxygen used, and percentage of carbon dioxide expired. Video tapes of each test were recorded to count the number of strides and breaths taken. Each subject was tested on a random assignment of test order.

There were no statistically significant differences in running efficiency and in the ventilatory parameters measured in this study between the controlled breathing pattern tests and the uncontrolled tests or between the individual time segments of those tests.

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APPENDIX A

INFORMED CONSENT

Respiration Efficiency Study

This study is a result of the visualization sessions you participated in during the fall of 1986, involving a respiration pattern. The purpose of the study is to compare the efficiency of the respiration pattern you practiced and your normal respiration pattern used while running at a high intensity and a moderate intensity.

The testing will consist of running on a treadmill for four (4) trials. The first two trials will last three (3) minutes each at a speed of 12.75 mph. The last two trials will last four (4) minutes each at a speed of 9.75 mph. A 10 minute rest will be given between each trial. The subject will be hooked up to a spirometry mouthpiece and will wear a nose clip for the purpose of measuring the amount of air ventilated through the body during the tests. In addition, a 3-lead ECG heart rate monitor will be worn.

All tests will be videotaped for the purpose of analyzing the ratio of strides per breaths. Prior to testing the subject will be asked to complete a biographical data questionnaire.

As a subject you are free to withdraw from the study at any time without penalty or prejudice. If you have any questions during the test they will be answered at the conclusion of the test.

I certify that I have read the preceding statement and understand the test I am to complete. I may withdraw from the study at any time.

Signature ______________________________

Date ______________________________

APPENDIX B

BIOGRAPHICAL DATA

Initials __________

Age __________

Height __________

Weight __________

Number of years running competitively (i.e., TAC/AAU, grade school, Jr & Sr high school, college)? __________

Number of months running at the collegiate level? __________

Number of months running at the post-collegiate level? __________

For the past year how many months have you run continuously (at least 5 days per week)? __________

Best time for: 800 meters __________

1500 meters __________

or mile __________

3000 meters __________

or 3200 meters __________

5000 meters __________

or 3 miles __________

APPENDIX B (continued)

BIOGRAPHICAL DATA RESPONSES

Subject	RAH	TJP	WCP	KMc	SAM	KLV
Age	21	20	18	20	26	24
Ht(cm)	175	175	177.5	172.5	177.5	180
Wt(kg)	63.55	66.75	68.45	58.00	69.90	67.80
#1 (in years)	9	10	10	10	14	10
#2 (in months)	6	18	7	15	60	60
#3 (in months)	0	0	0	0	33	10
#4 (in months)	9	12	12	10	12	8
Best time for 800m	2:05	2:04	1:53	2:03	2:09	1:58
1500m	4:20	--	3:59	4:02	4:10	3:51
mile	4:34	4:24	4:23	4:21	4:27	--
3000m	9:27	8:55	8:49	8:35	9:12	--
3200m	10:05	9:26	--	--	--	--
5000m	16:48	15:30	--	14:56	15:22	13:56
3-miles	15:30	14:41	--	--	--	--

APPENDIX C

METABOLIC MEASUREMENT PRINTOUT DATA SHEET Subject________kg____

Test #3 Protocol _____

VE (ml/min)							
VO_2 (ml/min)							
(ml/min/kg)							
VCO_2 (ml/min)							
R (R.Q.)							
% CO_2							
% O_2							
C							
V							
Time (period)							

Test #4 Protocol

VE (ml/min)							
VO_2 (ml/min)							
(ml/min/kg)							
VCO_2 (ml/min)							
R (R.Q.)							
% CO_2							
% O_2							
C							
V							
Time (period)							

APPENDIX D

HEART RATE AND BREATHS TABULATION SHEET **Subject** ____________

(seconds)

Test #1

	15	30	45	60	75	90	105	120	135	150	165	180
HR												
Breaths	X X		X X		X X		X X		X X		X X	

Test #2

	15	30	45	60	75	90	105	120	135	150	165	180
HR												
Breaths	X X		X X		X X		X X		X X		X X	

Test #3

	15	30	45	60	75	90	105	120	135	150	165	180
HR												
Breaths	X X		X X		X X		X X		X X		X X	
HR												
Breaths	X X		X X									
	195	210	225	240								

Test #4

	15	30	45	60	75	90	105	120	135	150	165	180
HR												
Breaths	X X		X X		X X		X X		X X		X X	
HR												
Breaths	X X		X X									
	195	210	225	240								

APPENDIX E

The ratio of strides:breaths for each subject during each test.

Subject	Test	Time Segments							
		30s	60s	90s	120s	150s	180s	210s	240s
RAH	1	5.14	4.57	4.00	4.04	4.00	4.36	4.00	4.04
	2 R_x	5.10	5.05	5.00	5.23	5.50	5.11	5.00	5.05
	3	4.24	4.00	4.00	4.03	4.04	4.00		
	4 R_x	5.00	5.00	5.00	5.00	5.00	5.00		
TJP	1	4.43	4.30	4.00	4.00	4.26	3.95	4.39	4.68
	2 R_x	6.13	5.81	5.38	6.12	5.52	5.47	6.50	5.58
	3	4.41	4.80	4.40	4.29	4.08	4.00		
	4 R_x	4.90	4.90	4.37	4.08	xx	xx		
WCP	1	4.93	4.11	3.90	3.70	3.09	3.19	3.00	3.28
	2 R_x	7.63	6.84	6.00	5.11	5.54	xx	xx	xx
	3 & 4	were not run							
KMc	1 R_x	4.30	4.00	4.31	4.13	4.08	4.42	4.17	4.66
	2	4.54	3.95	3.91	4.04	4.27	4.34	4.17	4.04
	3 R_x	Video tape did not work							
	4	4.16	3.77	3.59	3.29	3.23	3.16		
SAM	1 R_x	10.40	7.54	7.33	6.83	6.76	6.66	5.76	6.00
	2	4.61	4.19	4.30	4.30	4.36	4.09	4.10	4.04
	3 R_x	7.21	5.27	4.22	4.38	3.91	3.37		
	4	4.22	4.08	3.90	3.46	xx	xx		
KLV	1 R_x	8.88	8.70	8.30	9.00	9.33	9.22	8.80	8.75
	2	7.00	5.26	7.07	7.58	7.27	7.27	6.84	8.00
	3 R_x	8.40	8.16	7.54	6.61	7.30	6.00		
	4	7.07	6.06	5.44	5.31	5.93	5.41		