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A Comparison of the Effects of Two Different Respiratory Valves on Maximal Oxygen Uptake and Heart Rate Response of Selected Distance Runners

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A COMPARISON OF THE EFFECTS OF TWO DIFFERENT RESPIRATORY VALVES ON MAXIMAL OXYGEN UPTAKE AND HEART RATE RESPONSE OF SELECTED DISTANCE RUNNERS

by

Jeffry Phillip Morgan

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A COMPARISON OF THE EFFECTS OF TWO DIFFERENT RESPIRATORY VALVES ON MAXIMAL OXYGEN UPTAKE AND HEART RATE RESPONSE OF SELECTED DISTANCE RUNNERS

Jeffry Phillip Morgan, M.A.
Western Michigan University, 1982

This study compared selected cardiorespiratory responses obtained from two different respiratory valves, the Modified Otis-McKerrow and the Speak Easy, a mask-type valve, during maximal graded exercise testing of eleven distance runners. The results indicated that both maximal oxygen uptake and minute ventilation were significantly different. Values for maximal VO$_2$ and VE were lower with the Speak Easy by 24 and 19 percent, respectively. Further analysis revealed that those differences were significant at submaximal levels as well. The trends in those responses show that the differences increase with increasing workload. However, maximal and submaximal heart rates were not significantly different between the two valves. These findings seriously question the integrity of the Speak Easy mask for use in high level treadmill testing and indicate that valve leakage represents a major flaw in its ability to provide accurate data.
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Jeffry Phillip Morgan
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CHAPTER I
INTRODUCTION

The measurement of maximal oxygen uptake to assess cardiorespiratory fitness has been utilized consistently over the past three decades. Maximal oxygen uptake is still considered superior to any single item for evaluating physical work capacity (Astrand and Rodahl, 1977). Maximal graded exercise tests are generally employed in order to acquire oxygen uptake values. The use of exercise stress testing has increased due, in part, to its non-invasive diagnostic capabilities. Wilson, Bell, and Norton (1980) have suggested that cardiopulmonary diseases can be arrested, reversed, or even prevented by changes in lifestyle habits. This attitude has become quite prevalent, leading to the emergence of cardiac and pulmonary rehabilitation programs. Preventative exercise programs are also expanding to include the healthy adult populace. Stress testing continues to be used in the Olympic movement and in major college human performance laboratories. Testing provides feedback on specific sports and training regimens, while aiding in the screening of gifted athletes.

Measuring maximal oxygen uptake requires the use of complicated and expensive equipment. It is often difficult for rehabilitation programs and testing laboratories to afford the necessary instrumentation. As a result, exercise physiologists and related health care professionals have relied on published studies to estimate maximal oxygen uptake. Bruce (1971) proposed that oxygen uptake could be predicted by the maximal...
time an individual could walk in the Bruce treadmill protocol. This led him to construct a nomogram for predicting maximal oxygen uptake. The advantage of this nomogram, and others (Workman and Armstrong, 1963), is that it does not require the collection and analysis of expired air. However, studies indicate that the use of such nomograms for predicting maximal oxygen uptake is questionable (Froelicher and Lancaster, 1973; Froelicher, Thompson, Davis, and Triebwasser, 1975). More recently, Jago (1980) found that predicted values overestimate the capacities of cardiac patients by fourteen percent.

It is becoming apparent that actual collection and measurement of expired air is required in order to accurately assess the individual being studied. Collecting expired air for the determination of oxygen uptake requires the use of a respiratory valve. In most cases, a mouthpiece is attached directly to the valve through which the subject breathes during an exercise test. There exists a wide variety of established respiratory valves, many of which exhibit unpleasant qualities. Some valves are burdensome to the subject and may cause chaffing of the gums (Jakeman and Davies, 1979). Ellis and Lampman (1976) reported that many valves cause feelings of confinement and restraint on the part of the subject. Additional sources of discomfort evolve from alterations in normal ventilation, thus effecting exercise performance (Lenox and Koegel, 1974). These restraints might create noticeable limitations on performance, in addition to effecting key variables being measured during the test.
In an attempt to reduce the number of undesirable characteristics inherent in many valves, some researchers have developed and tested their own hybrid valves (Lenox and Koegel, 1974; Jakeman and Davies, 1979). Although the World Health Organization has made recommendations with respect to respiratory valve performance attributes (Andersen, Shephard, Denolin, Varnauskas, and Masironi, 1971), newer valves are being developed and marketed without adequate evaluation. As a consequence, there exists a potential for questionable data obtained from such devices. Jones and Kane (1979) pointed out that quality control in exercise test measurements is possible only when established, reliable equipment and procedures are incorporated into the testing environment. Researchers are encouraged to make preliminary oxygen uptake measurements on valves they intend to utilize in order to avoid the problems leading to inaccurate data (Lenox and Koegel, 1974; Jakeman and Davies, 1979).

Statement of the Problem

The problem involved in this study is to compare selected cardiorespiratory responses between a well-established respiratory valve, the Modified Otis-McKerrow and the Speak Easy, a mask-type valve, during maximal graded exercise testing of selected distance runners.

Purpose of the Study

The purpose of this study is to determine the differences in measured responses between the valves being studied in order to identify the undesirable characteristics in question. Specific objectives were:
1. To further substantiate the World Health Organization's recommendation that mask-type valves be avoided in gas collection procedures,

2. To objectively observe and evaluate the performance of the Speak Easy mask at maximal exercise levels to determine its practicality in a high level testing environment, and

3. To aid in the selection of a valve that will be comfortable to the subject, yet provide accurate data.

**Significance of the Study**

The problems encountered with existing respiratory valves has created a demand for more improved valves. New valves on the market will need to be tested under several exercise conditions to properly assess their performance against established apparatus. In this study, a comparison between the performances of a recent, but relatively unstudied, respiratory valve and an established valve may aid in the evaluation of similar valves under exercise testing conditions as well as identifying possible flaws in their design.

**Delimitations**

The study was delimited to eleven distance runners from the Western Michigan University track team. The dependent variables were delimited to maximal oxygen uptake (ml/kg/min), heart rate, and minute ventilation (post hoc). Due to the unavailability of special instrumentation, the study was delimited to a comparison of the Modified Otis-McKerrow and the Speak-Easy.
Limitations

The study was limited to the following:

1. Because of the time and cost restraints, sample size was limited to eleven subjects.

2. Since subjects were not selected at random, they will represent an intact group. Inferences made to similar populations becomes limited.

Research Hypothesis

It is hypothesized that measurements for maximal oxygen uptake will be significantly lower for the Speak Easy. It is also postulated that maximum heart rate will be significantly lowered when utilizing the Speak Easy. Minute ventilation may exhibit a lower value with the Speak Easy as well.

Definitions

Several terms used in the text of this study are specific to the topic being discussed and require special consideration as to their correct interpretation. These terms are defined below.

Speak Easy valve (mask): A lightweight respiratory valve that encloses the nose and mouth due to its mask-like design (Wilson, Rivington, and Fischer, 1980).

Anatomical dead space: The internal volume of the airway, from the mouth to the respiratory bronchioles (Young and Crocker, 1976).
Mechanical dead space: A functional extension of anatomic dead space due to space inherent in breathing apparatus (Egan, 1977). In this study, dead space will refer to mechanical dead space.

External airflow resistance: The additional resistance to airflow imposed on the individual and evident in the static pressure drop across both inspiratory and expiratory orifices in a respiratory valve (Lenox and Koegel, 1974).

Modified Astrand treadmill protocol: A modification of the Astrand protocol. In this instance, the first stage lasts three minutes, with each successive stage lasting two minutes. Speed is maintained at 8.5 mph. Elevation begins at 2.5 percent and increases by that amount each additional stage (Pollack, 1976).
CHAPTER II
REVIEW OF LITERATURE

This chapter is devoted to a review of the literature as it relates to this study. Five areas will be addressed in this section: (a) Measuring Maximal Oxygen Uptake; (b) Predicted Versus Actual Measurement of Oxygen Uptake; (c) Characteristics of Respiratory Valves; (d) A Comparison of the Modified Otis-McKerrow Valve and the Speak Easy Mask, and (e) a brief summary of the review, included at the end of the chapter.

Measuring Maximal Oxygen Uptake

Mitchell and Blomqvist (1971) have defined maximal oxygen uptake (max VO$_2$) as:

The greatest amount of oxygen a person can take in during physical work and is a measure of his maximal capacity to transport oxygen to the tissues of the body. (p. 1018)

It is well known that maximal oxygen uptake is of physiologic importance because it requires the combined involvement of the respiratory, cardiovascular, and neuromuscular systems. Max VO$_2$, therefore, provides quantitative information as to an individual's capacity to carry on physical work over a prolonged period of time.

In 1926, A. V. Hill demonstrated that there was an observable upper limit of the cardiorespiratory system to supply oxygen to the working muscles. There have been several investigations confirming
the validity and reliability of maximal oxygen uptake as a measure of one's capacity for aerobic energy transfer.

Taylor, Buskirk, and Henschel (1955) conducted measurements of maximal oxygen uptake on 115 subjects. Their results proved that max \( \text{VO}_2 \) was not only reliable, but that it was sensitive to changes in aerobic capacity when test conditions are standardized.

In a report on maximal oxygen uptake, Mitchell and Blomqvist (1971) point out that the use of max \( \text{VO}_2 \) as an indicator of functional capacity is well documented. McArdle, Katch, and Katch (1981) expressed the view that because it has been shown to be both reliable and valid, maximal oxygen uptake has become one of the fundamental measures in exercise physiology.

A stress test is employed in order to elicit a maximal oxygen uptake. The test may utilize bench stepping, arm or bicycle ergometer, or motor-driven treadmill. A continuous treadmill protocol appears to be a more satisfactory means for acquiring max \( \text{VO}_2 \) (Taylor, et al., 1955; Bruce, 1971; Blomqvist, 1971; and McArdle et al., 1981). During the stress test, expired air is collected and analyzed. The point at which oxygen uptake plateaus with additional workloads has been defined as maximal oxygen uptake (Mitchell and Blomqvist, 1971; Andersen et al., 1971; and McArdle et al., 1981).

Predicted Versus Actual Measurement of Oxygen Uptake

In order to measure oxygen uptake directly, special metabolic equipment is required. The cost of such instrumentation makes it
unaffordable for many testing facilities. In response to this problem, researchers have devised nomograms and equations for predicting oxygen uptake without the need for expensive metabolic analyzers.

Workman and Armstrong (1963) developed a nomogram, predicting oxygen uptake in liters per minute for treadmill walking. Their nomogram was based on the results of testing ten healthy subjects. After testing an additional 44 subjects, they found their nomogram to have a correlation coefficient of .935.

Bruce (1971) studied 148 men and 144 women with respect to max \( \text{VO}_2 \). He concluded that maximal oxygen uptake could be predicted from age, activity status, and more importantly, total length of time exercised on the Bruce treadmill protocol.

Other studies have been conducted in order to develop graphs and equations for predicting oxygen uptake in a variety of activities. The American College of Sports Medicine (1980) has combined many of these studies and has published a table of estimated energy expenditure in METs during treadmill walking and running at various speeds and grades. These values are widely used and accepted by many testing facilities.

More recent studies have challenged the use of predicted values. Froelicher and Lancaster (1974) calculated a regression line for oxygen uptakes in 1,025 normal men. Tolerance limits of 95 percent were selected. Oxygen uptake values deviated as much as 5 METs (17.5 ml/kg/min) above or below the regression line. It was concluded that maximal performance time could only grossly predict maximal oxygen uptake,
therefore, actual measurement was required to accurately determine functional capacity.

In an attempt to further substantiate the opinion that max VO\textsubscript{2} could not be adequately predicted from performance time, Froelicher et al. (1975) tested 79 men using the Balke treadmill protocol and 77 men using the Bruce treadmill protocol. Two regression lines were constructed in conjunction with 95 percent tolerance limits. The Bruce and Balke protocols were found to have r values of .87 and .80, respectively. The authors concluded that since other factors besides maximal treadmill time are operative in determining max VO\textsubscript{2}, the value of nomograms is questionable.

Adams, Marlon, and Quinn (1980) conducted stress tests on 65 patients with coronary artery disease. Their purpose was to investigate the relationship between predicted and measured symptom limited maximal oxygen uptake. A significant difference between predicted and measured oxygen uptake was found in 52 patients (80%). Predicted values were significantly greater (p < .05) than the measured values. The results also revealed a 20 percent disparity between predicted and measured values throughout the test protocol.

Jago (1980), in an unpublished Master's thesis, compared actual measurements to predicted values established by the American College of Sports Medicine in 230 cardiac patients. He found that measured and predicted oxygen uptakes differed significantly during each stage of the protocol above 5 METs. The difference appeared to increase with increases in workload. On the average, predicted values tended to overestimate actual values by 14 percent. It was concluded that
predicted values set forth by the American College of Sports Medicine do overestimate the capacities of patients with coronary heart disease.

**Characteristics of Respiratory Valves**

In a report for the World Health Organization, Andersen et al. (1971) recommended that maximal oxygen uptake be measured directly. Direct measurement of oxygen uptake appears to be further supported where the failure of nomograms to accurately predict those values among cardinals has occurred (Adams et al., 1980; Jago, 1980). Direct measurement of oxygen uptake requires the use of a respiratory valve or mask device. However, respiratory valves entail certain elements that may alter the physiological variables being observed during an exercise stress test. The characteristics to be addressed at this point involve discomfort, leakage, dead space, and external airflow resistance (both inspiratory and expiratory).

**Discomfort.** Ellis and Lampman (1976) identified anxieties in test subjects due to feelings of confinement and restraint as a result of set-ups used for supporting the valves. Many of the support structures inhibit the natural movement of the subject, thus creating discomfort. The Otis-McKerrow is a commonly used valve which is heavy (350 grams) and bulky, requiring a detailed supporting structure. It has been reported that the Otis-McKerrow valve causes chaffing of the gums at high workloads (Jakeman and Davies, 1979). Lenox and Koegel (1974) reported that restrictions in natural head movements measureably increase
the work required to maintain valve control as well as creating jaw
t fatigue. In some instances, respiratory valves may lead to complaints
of mouth dryness or excessive salivary buildup.

**Leakage.** Leakage represents another problem with respect to
respiratory valves. There are few, if any, studies directly addressing
this problem, but several investigators have reported leakage in some
respiratory valves. Lenox and Koegel (1973) reported leakage in both
the Triple-J and Modified Otis-McKerrow valves. The Modified Otis-
McKerrow valve operated with no leakage when supported in a vertical
plane, but lost up to 2 percent through the inspiratory side when
supported horizontally. This leakage did not appear significant enough
to effect the measured variables. Leakage was more pronounced in the
Triple-J, even at low workloads. Alterations in the valve were necessary
to avoid excessive leakage. Flook and Kelman (1973) experienced some
leakage of air into the valve unit of the Modified Otis-McKerrow, but
not enough to alter the collected data.

Andersen et al. (1971) expressed concern over the use of face
masks and their inability to provide an adequate seal around various
facial types. In a comparative study utilizing a Speak Easy mask,
Wilson et al. (1980) reported that in both lung function and bicycle
ergometry testing, no leakage occurred with the mask.

**Dead Space.** All respiratory valves entail a certain amount of
dead space. Dead space is a concern to the investigator because of
problems associated with the rebreathing of carbon dioxide inherent in
the expired air of the dead space. As a result, the effects of dead space on cardiorespiratory responses at rest and exercise have been conducted.

Bouhuys, Jonsson, and Gunner (1957) studied five subjects in an attempt to identify the effects of added dead space on resting ventilation. Each subject was tested with a breathing valve (assumed to represent no dead space), 260 ml added dead space, and 480 ml added dead space. An open-circuit nitrogen wash-out method was used which allowed a continuous recording of end-tidal nitrogen concentrations. Additional dead space did not consistently change the respiratory rate, however, slight increases were observed. Dead space did increase tidal volume almost equal to the amount of dead space. A regression equation of dead space on tidal volume showed that the dead space was, on the average, 20 percent of the tidal volume. It was concluded that the efficiency of the lungs proper were not impaired by the additions of dead space.

The effects of added dead space during exercise were investigated by Jones, Levine, Robertson, and Epstein (1971). A Lloyd valve containing 48 ml dead space was used for the collection of control data. Added dead space of 700 ml and 1400 ml were given to four subjects. Exercise data was measured at workloads of 300, 500, 600, 900, and 1100 kpm/min. The results showed no consistent effect of added dead space on carbon dioxide production (VCO$_2$) or oxygen uptake. Again, minute ventilation (V$_{E}$) increased with increasing dead space. It was suggested that the response to additional dead space is related to individual differences in the resting responsiveness to carbon dioxide.
To assess the effect of respiratory valve dead space on ventilation at rest and exercise, Bartlett, Hodgson, and Kollias (1972) examined four commonly used valves in five subjects. The valves included the Triple-J, Modified Otis-McKerrow, Lloyd, and Single-J containing 300, 215, 48, and 36 ml dead space, respectively. Subjects were tested at rest and during submaximal and maximal exercise. No significant difference in oxygen uptake was found between any of the valves. Expired volumes did increase with increasing dead space. According to their data, it was suggested that a significant increase in ventilatory volume could be expected with an increase in valve dead space beyond a 50 ml limit.

Bolen (1981) studied a group of 11-12 year old boys in order to determine the effect of dead space on oxygen uptake. He utilized a Modified Otis-McKerrow valve (215 ml) and a Hans-Rudolph valve (18 ml). Results agreed with previous studies. Respiration rate, max VO$_2$, and expired ventilation volume were not significantly different between the valves.

Ward and Whipp (1980) studied the effects of dead space by interposing a cylindrical tube between a Lloyd valve and mouthpiece. Tube volumes provided dead space of .1, .2, .4, and .7, and 1.0 liter. Minute ventilation, carbon dioxide output, and mean alveolar PCO$_2$ were measured at steady state during bicycle ergometry. Mean alveolar PCO$_2$ increased in direct proportion to external dead space volume. Only at the largest dead space volumes could ventilatory inadequacy be detected, but insignificantly. Hyperpnea appeared to be the only ventilatory
compensation brought on by the increased external dead space. It was concluded by the authors that increments in dead space increased ventilation due to an increased airway CO$_2$ load. Furthermore, the ability of exercise hyperpnia to regulate PCO$_2$ in response to added metabolic demands was not hampered by additional dead space. It was suggested that other sources could account for the hyperpnia observed, namely, increased apparatus resistance.

**External airflow resistance.** One of the most studied characteristics of respiratory valves is external airflow resistance. Studies involving military field masks, industrial cannisters, and increments of resistance added to conventional respiratory valves have been conducted to assess the effects of external airflow resistance on key cardiorespiratory responses. As a result, researchers have paid special attention to the role of external airflow resistance as it relates to the collection of those values. In fact, Andersen et al. (1971), in a report for the World Health Organization, suggested that respiratory valves should not contain more than 50 ml dead space nor exceed a resistance of 5 cm H$_2$O at a flow rate of 300 l/min. It was further suggested that face mask apparatus be avoided due to potential for leakage.

Silverman, Lee, Yancey, Amory, Barney, and Lee (1945) published a report on resistance in industrial protective equipment. 157 subjects were tested on a bicycle ergometer at a variety of workloads representing submaximal exercise. Inspiratory resistances of up to 106 mm H$_2$O and expiratory resistance up to 76 mm H$_2$O at a flow rate of 85 l/min were employed. It was found that when resistance is added to either
inspiratory or expiratory sides, it lengthens that portion of the cycle to which resistance is added. It was concluded that resistances up to the maximum values used did not, separately, hinder the performance of completion of 15 minutes of heavy work (830 kg/min). In a follow-up study, Silverman, Lee, Plotkin, Sawyers, and Yancey (1951) investigated airflow resistance in an additional 18 male subjects. This study showed that oxygen uptake was reduced significantly at workloads above 830 kg/min. Increased resistance decreased minute ventilation almost 20 percent at the two highest workloads.

Three respiratory protective devices and a 'no mask' control group were used in a study conducted by Thompson and Sharkey (1966). Each subject was tested on a treadmill at a constant speed with increases in grade throughout the test. Exercise heart rates and recovery oxygen uptake were recorded. Resistances for inspiratory and expiratory sides ranged from 1.5 to 3.0 inches H$_2$O and .72 to .93 inch H$_2$O respectively at a flow rate of 85 l/min. Mean oxygen uptakes during recovery were significantly lower for the higher resistance conditions. It was concluded that the increased resistance, coupled with excessive heat, could limit the ability to continue vigorous activity.

VanHuss and Heusner (1965) found a number of problems due to added resistance. They investigated the respiratory burden of the M17 field protective mask. Several exercise conditions representing aerobic and anaerobic work were utilized. Four resistance conditions, including a no-mask control, were employed. Resistance conditions ranged from a low of no resistance (bareheaded) to a high resistance involving an
inspiratory resistance of 50 mm H$_2$O and an expiratory resistance of 35 mm H$_2$O at a flow rate of 100 l/min. In a continuous treadmill run to exhaustion, total time was significantly decreased in the high resistance conditions. Heart rates throughout the run were significantly lower for each increment in resistance. Results from a standard treadmill run revealed an impairment of minute ventilation and respiratory rate with increased resistance. It was concluded that in the conditions involving a higher aerobic component, the performance times differentiate respiratory conditions. High respiratory resistance under heavy work conditions appears to reduce work performance in longer tasks, heart rates throughout exercise, maximal heart rate, minute volume, oxygen uptake, and oxygen pulse. Conversely, added resistance increases oxygen uptake per liter ventilation and oxygen debt.

In a similar study, Stemler and Craig (1977) found identical responses. They tested 12 enlisted men using M9 and M17 field masks. Resistances, expressed as inspiratory/expiratory at a flow rate of 4 l/sec ranged from 0/0 to 148/60 mm H$_2$O. Each subject was exercised to volitional fatigue. Endurance times were reduced for each increment of resistance. Maximal heart rates and respiration rates were also decreased. The authors concluded that there was a regular relationship between resistance and endurance, and that there was little room for error from other sources such as dead space. They also found that resistance lengthens the portion of the cycle that resistance is added.

Trethewie (1947) observed a decrease in heart rate with increased resistance. He studied 12 subjects using a high and low resistance
respiratory cannister. Exercise conditions involved longer duration exercise and short duration (anaerobic) exercise. Effects of the higher resistance cannister became a factor only during prolonged exertion. Mean pulse rates were decreased under conditions utilizing the high resistance cannisters and subjects were not able to do as much work. Trethewie suggested that the higher resistance cannister increased intrathoracic pressure, allowing a greater output of the heart rate per beat, causing a lowering of the heart rate for the same output.

In another study employing M9 field masks, Craig, Blevins, and Cummings (1970) evaluated 12 enlisted men under three exercise conditions. Dead space ranged from 100 to 300 ml. Additional resistance was made by placing layers of muslin and wire mesh between the inspiratory valve and pneumotach. A second expiratory valve placed over the first provided additional expiratory resistance. Their results were in agreement with Vanhuss and Heusner (1965) and Stemler and Craig (1977). Oxygen uptake was significantly impaired with increased inspiratory resistance. Time to exhaustion was also decreased with added external resistance.

Cerretelli, Sikand, and Farhi (1969) studied added resistance in two subjects. They used four resistance conditions with a range in inspiratory/expiratory of 26/22 to 62/40 cm H₂O. Minute volume decreased with each increase in resistance. Max VO₂ and exercise tolerance were decreased as well. They concluded that "the ventilatory response to exercise under conditions of increased airway resistance is neither a minute volume response nor a work of breathing response, but falls between the two" (p. 597). A similar finding was reported by Hermansen,
Vokac, and Lerein (1972). They tested 10 subjects utilizing an M9 mask and a respiratory valve. Subjects were tested on a bicycle ergometer at submaximal workloads of 300, 600, 900, and 1200 kpm/min. Pulmonary ventilation was lower at each workload with the higher resistance mask. In fact, at maximal workload, ventilation was found to be 43 percent lower. Oxygen uptake at maximal work was significantly decreased \( (p < .001) \) with the high resistance mask. However, no significant difference was found at peak workloads for heart rate.

Demedts and Anthonisen (1973) investigated the effects of increased resistance during steady state exercise. Resistances were added to an Otis-McKerrow valve with the control resistance represented by the valve and breathing circuit alone. Six subjects exercised at workloads between 500-1650 kgm/min. Ventilation was reduced by 12 percent at the highest workloads between the two lower resistance conditions. However, a substantial decrease in ventilation as well as maximum level of work performance was found in the highest resistance. It was concluded that the amount of exercise limitation imposed by a given external resistance appeared to depend, first, on the ventilatory limitations produced by the resistance and, second, on the CO\(_2\) responsiveness of the individual to that ventilatory limitation.

In a study involving eleven 16-year old boys, Flook and Kelman (1973) employed three different levels of inspiratory resistance during submaximal bicycle ergometry. Inspiratory resistances of 8.9, 16.5, and 53.1 cm H\(_2\)O at a flow rate of 1 l/sec were added to a Modified Otis-
McKerrow valve. Each subject was tested at three submaximal workloads estimated at 35, 50, and 70 percent of their maximum predicted heart rates under each of the inspiratory resistance conditions described. A no resistance condition was included to serve as a control. The results showed that both heart rate and oxygen uptake at all workloads were not significantly different, but both variables fell initially and then increased with progressive resistance. Minute ventilation was shown to decrease with additional resistance. At the highest workload, there was a slight decrease in oxygen uptake, but it was not statistically significant.

Lastly, Dressendorfer, Wade, and Bernauer (1977) studied three curvilinear inspiratory resistances on seven trained men. Breathing resistance was added to a Daniels valve, resulting in a range of inspiratory resistance from 2 to 84 cm H2O at a flow rate of 4 l/sec. Increased resistance did not significantly alter anaerobic threshold. Reductions in ventilation were accompanied by decrements in maximal oxygen uptake. As resistance increased, max VO2, endurance time, and heart rate were all significantly lower. The authors concluded that their data suggests that increased resistance restricts work tolerance before a true anaerobic limit is reached.

**Modified Otis-McKerrow Versus Speak Easy**

The Modified Otis-McKerrow valve is a widely used respiratory valve. Part of its popularity revolves around its low resistance properties at high flow rates. The Werner E. Collins Company lists resistance at 1, 2, 4, 6, 9, and 15 cm H2O for flow rates of 100, 200,
300, 400, 500, and 600 l/min, respectively. The Modified Otis-McKerrow valve falls well within the recommendations set forth by the World Health Organization (Andersen et al., 1971), in terms of resistance.

Perhaps its main disadvantages are volume of dead space and weight (Jakeman and Davies, 1979). In a study on respiratory valve dead space, the Otis-McKerrow was shown to provide reliable gas analysis data, despite its dead space (Bartlett et al., 1972). Other studies involving dead space have shown that even extreme volumes of dead space have negligible effects on key cardiorespiratory measures (Jones et al., 1971; Ward and Whipp, 1980).

The design and weight of the valve have been a problem as noted by Lenox and Koegel (1974), but there has been no documentation showing that its bulkiness effects physiological testing data.

A number of studies in the present review have utilized the Otis-McKerrow because of its reliability. Demedts and Anthonisen (1973) used the valve as their control resistance condition. Minute ventilation and oxygen uptakes appeared consistent when compared to the higher resistance conditions. Heart rate and other variables obtained using this valve provided acceptable baseline data. In the report by VanHuss and Heusner (1965), the Otis-McKerrow was inserted into the field mask to provide a low resistance condition, one step up from the bareheaded controls. Results showed remarkable similarity between heart rate and performance time between the Otis-McKerrow and the bareheaded control data. Aside from the bulkiness inherent in the Otis-McKerrow valve, it can be assumed that it remains a viable piece of exercise testing equipment.
Conversely, the Speak Easy mask is fairly new and has very little technical data available on it. It overcomes the weight and bulkiness of the Otis-McKerrow, but entails questionable resistive and leakage properties, due to its mask-like design. The World Health Organization (Andersen et al., 1971) stated that masks are difficult to use in exercise testing because of dead space and leakage.

In an unpublished study comparing the Speak Easy with other widely used valves, Wilson et al. (1980) tested six subjects at rest, while performing lung function tests, and at exercise on a bicycle ergometer. They found no differences between the mask and the other two valves with respect to minute ventilation and oxygen uptake. It was also reported that no leakage occurred with the Speak Easy. However, in preliminary testing for this study, VanHuss found substantial differences in inspiratory resistance between the Modified Otis-McKerrow and the Speak Easy. Leakage, although not directly measured, was noticed with the use of the Speak Easy mask. Descriptive data is presented in Chapter III. With the lack of information available on the Speak Easy mask, and the fact that the available information is conflicting, it would appear that further testing of the mask is warranted.

**Summary**

Determination of functional capacity, assessment of cardio-respiratory responses, documenting ECG changes to exercise, and defining the results of medical intervention serve as objectives for exercise testing (Bruce, 1971). The measurement of maximal oxygen uptake provides
the exercise physiologist and physician with quantitative information with respect to the amount of work an individual is capable of doing. Direct measurement is more acceptable, especially in cardiac patients, due to the inability of predicted values to accurately estimate oxygen uptake.

Direct measurement requires the use of a respiratory valve. Certain characteristics of those valves can alter the results of the test. Discomforts brought on by heavy and bulky valves and the support structures required have been identified (Lenox and Koegel, 1972; Jakeman and Davies, 1979). According to the studies in this review, dead space does not appear to have a significant impact on a subject's ability to perform exercise. It was shown that pulmonary ventilation was increased in proportion to an increase in tidal volume. No significant differences were noted for max VO$_2$ (Jones et al., 1971; Bartlett, et al., 1972; and Ward and Whipp, 1980). On the other hand, increased airflow resistance was shown to effect some key responses. Many of the studies showed decreases in heart rate, oxygen uptake, and endurance time with increases in external airflow resistance, or a combination of those three variables (Van Huss and Heusner, 1965; Cerretelli et al., 1969; Craig et al., 1970; and Dressendorfer et al., 1977). Ventilation was also shown to decrease as resistance was increased (Silverman et al., 1951; Van Huss and Heusner, 1965; Cerretelli et al., 1969; Flook and Kelman, 1973; and Dressendorfer et al., 1977). In addition to external airflow resistance, leakage was identified as a potential source of measurement error (Andersen et al., 1971).
The Modified Otis-McKerrow valve appears to be a well established, low resistance breathing apparatus. The Speak Easy mask has not been studied in depth. The information that does exist is conflicting. It would seem appropriate to compare the Speak Easy mask to the Modified Otis-McKerrow valve in order to assess the mask's practicality in collecting selected cardiorespiratory responses.
CHAPTER III
DESIGN AND METHODOLOGY

The purpose of this study was to compare cardiorespiratory responses obtained from an established respiratory valve and a mask-type valve of questionable integrity. This chapter contains five sections: (a) Subject Selection; (b) Pilot Study; (c) Instrumentation; (d) Data Collection; and (e) Statistical Analysis.

Subject Selection

Eleven distance runners from the Western Michigan University track team volunteered for this investigation. Criteria established in the selection of the observed group are: (a) Those runners having a completed physical exam by the school physician; (b) Individuals approved by the Western Michigan University Human Subjects Board; (c) Those runners between the ages of 18 and 23 years; and (d) Runners maintaining a weekly regimen of at least 30 miles. Physical characteristics of the subjects with respect to age, height, weight, and training mileage are presented in Table 1.

Table 1
Physical Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>X</th>
<th>± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>69.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Mileage (miles/week)</td>
<td>51.4</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Note. n=11

25
Pilot Study

A pilot study was conducted at Michigan State University to provide additional information on the Speak Easy mask under exercise conditions. Comparisons were made between the Modified Otis-McKerrow valve and Speak Easy mask with respect to inspiratory resistance, expiratory resistance, respiratory rate, oxygen uptake, and minute ventilation.

Inspiratory and expiratory resistances were measured by inserting a plug with a 3/16 inch inside diameter into both valves. A 3/8 inch diameter plastic tube was attached to the plug and to a Sanborn 268A pressure transducer mounted two feet above the head of the subject. Pressure recordings were collected during exercise using a Sanborn Twin-Viso recorder with strain gauge amplifier. Calibrations were made using a water manometer connected into the circuit with a T-tube.

The standard open circuit Douglas bag method was utilized for collecting expired air. Oxygen and carbon dioxide percentages were measured using the flow-through technique directly from the bag. A Beckman OM-11 oxygen analyzer and LB-2 carbon dioxide analyzer were employed for gas analysis purposes. Gas volumes were measured with a Singer-American DTM-115 at a constant flow rate of 50 l/min.

Three graduate students participated in the testing. The protocol called for three workloads with speed and grades being established at six mph and zero percent grade, six mph and five percent grade, and seven mph and six percent grade, respectively. After random assignment to a particular valve, the subjects proceeded with the test on an A.R. Young motor-driven treadmill. The same subjects repeated the test one week later with the opposite valve.
Table 2 represents valve characteristics compiled from the literature and the pilot study. Mean values for the inspiratory resistance at the highest workload (7mph-6% grade) appear to be the largest discrepancy. At that point, the Speak Easy mask entailed almost 33 percent greater inspiratory resistance (36.3 versus 11.9 mm H₂O) than the Modified Otis-McKerrow valve. Inspiratory resistance was further partitioned into mean values at each of the three treadmill stages and is illustrated in Figure 1.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Otis-McKerrow</th>
<th>Speak Easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (gm)</td>
<td>353ₐ</td>
<td>54.2ₐ</td>
</tr>
<tr>
<td>Dead space (cm H₂O)</td>
<td>115ₜ</td>
<td>110ₗ</td>
</tr>
<tr>
<td>Mean Inspiratory Resistance (mm H₂O @ 20°C)</td>
<td>11.9 ± 3.86</td>
<td>36.3 ± 9.15</td>
</tr>
<tr>
<td>Mean Expiratory Resistance (mm H₂O @ 20°C)</td>
<td>22.5 ± 8.02</td>
<td>23.6 ± 6.66</td>
</tr>
<tr>
<td>Mean VE (l/min)</td>
<td>81.9 ± 16.65</td>
<td>78.5 ± 18.99</td>
</tr>
</tbody>
</table>

**Note.** n=3

ₐWeights were obtained from Borgess Medical Center using an Ohaus triple beam scale (2610 gram capacity).

ₜAs listed, with vane, by the Werner E. Collins Company.

ₗAs reported by Wilson, et al., 1980.
Figure 1. Inspiratory Resistance at Three Workloads

Instrumentation

Treadmill protocol. A modification of the Astrand treadmill protocol (Pollack, 1976) was administered to the subjects in both tests. All treadmill tests were conducted on a Quinton model 18-49-C motor-driven treadmill. Each subject was progressively exercised to volitional fatigue, unless required to stop due to abnormal electrocardiographic or blood pressure changes. Subjects were instructed not to
hold onto the treadmill guardrail, except as needed to maintain balance. A modified Astrand protocol is presented in Appendix A.

**Respiratory gas analysis.** Expired air was collected every thirty seconds during the exercise test. A Beckman Metabolic Measurement Cart (MMC) was used to collect and analyze the expired gases as described by Wilmore, Davis, and Norton (1976). In this system, expired air was drawn from the mixing chamber through a drying column before analysis. Analysis was made by a Beckman OM-11 oxygen analyzer and a Beckman LB-2 carbon dioxide analyzer. A constant flow rate of 500 ml/min was maintained throughout the analysis. A turbine device determined expired air volumes as gas flowed through a transducer. A sensor located at the outlet of the volume transducer provided expired air temperature. A programmable calculator, receiving information from an electronic interface, computed pertinent data. Before each test, the MMC was calibrated according to four basic procedures: a) adjustment of flow rate to 500 ml/min and checking pressure gauge; b) calibrating bias flow to ensure the integrity of the turbine and volume transducer; c) calibration of volume gain by insertion of a 1 liter syringe into a Hans-Rudolph valve and forcing through 10 liters in a 20 second span. A comparison was made to the digital readout which provides feedback for adjusting the volume gain; and d) calibration of the OM-11 and LB-2 was made by using gases of a known concentration. Adjustments were made until analyzer values equaled the known gas values.
Electrocardiography. Before each test, each subject was prepared with a standard 12-lead electrocardiogram. The subject was connected to a three channel Viagraph recorder with oscilloscope. Electrocardiographic recordings were taken at standing rest, prior to the end of each treadmill stage, at the point of volitional fatigue, and at two minute intervals post-exercise until the subject had recovered to a heart rate less than 100 beats/min. The ECG was monitored for abnormal responses such as S-T segment depression and arrhythmias. Subjects wore a mesh vest to minimize artifact on the ECG recordings. Heart rates were calculated by measuring R to R intervals with a standard ECG ruler (Cooper Labs, Wayne, New Jersey).

Data Collection

Eleven distance runners were tested during a four week period. The subjects were grouped into two sets, with each set being tested in a two week period. Each subject was tested one week apart in order to minimize any training effects (Astrand and Rodahl, 1970). Environmental conditions were recorded before each test. Wet bulb, dry bulb, and relative humidity were determined by a Bacharach model 12-701 sling psychrometer. Barometric pressure was measured with a Princo Nova mercurial barometer. Blood pressure was determined by auscultation using a stethoscope and sphygmomanometer (Trimline, PyMaH Corp., Somerville, New Jersey). Measurements were taken and recorded one minute before the end of each stage, during exercise, and every other minute during the recovery period.
An informed consent was signed before the start of the testing procedures. A copy of pre-test instructions and informed consent is provided in Appendix B and C, respectively. Each subject was randomly assigned to either the Modified Otis-McKerrow valve or the Speak Easy mask, thus controlling the effect of order. The order was reversed for the second testing. Subjects had been instructed to wear loosely fitting gym shorts and running shoes. Each subject followed a standard warmup procedure involving 1/2 mile easy jogging and stretches for the quadriceps, Achilles tendon, and calf muscles. Subjects were also instructed that termination of the test would not be allowed for reasons pertaining to the restriction or inhibition they may have about the respiratory valves. A copy of the data collection sheet is presented in Appendix D.

**Statistical Analysis**

Raw data was coded with respect to the type of valve used and the dependent variables measured. The coded information was analyzed, by computer, at Western Michigan University. Descriptive statistics were computed for maximum oxygen uptake ($\dot{V}O_2$ ml/kg/min), heart rate, minute ventilation ($\dot{V}E$ l/min), oxygen uptake ($\dot{V}O_2$ l/min), carbon dioxide production ($\dot{V}CO_2$ l/min), respiratory exchange ratio (RQ), respiratory rate (breaths/min), systolic and diastolic blood pressure, and test duration. A dependent (correlated) $t$ test was utilized to determine whether a significant difference occurred between the valves for maximal oxygen uptake (ml/kg/min) and maximal heart rate. A post hoc $t$ test
was computed for minute ventilation at maximal exercise. The null hypothesis was tested at the .05 level of confidence.

After reviewing the submaximal data, it was decided to investigate differences between the valves throughout the treadmill protocol on a stage by stage basis. The statistical analysis is described in the Post Hoc Results section of Chapter IV.
CHAPTER IV
RESULTS AND DISCUSSION

This chapter includes the results and a discussion of the cardiorespiratory responses obtained from two different respiratory valves during maximal graded exercise testing of 11 selected distance runners. The purpose of this study was to compare differences in frequently measured variables between a well established respiratory valve, the Modified Otis-McKerrow and the Speak Easy, a mask-type valve, during maximal exercise conditions. This chapter contains: (a) Results, (b) Post Hoc Results, and (c) a Discussion of the results.

Results

Ambient conditions during testing was fairly stable with the mean temperature (± standard deviation) recorded as 24.6 ± .94° C. Mean relative humidity was 53.73 ± 8.3%. Mean barometric pressure was measured at 741.04 ± 6.91 mmHg. Subject raw data at maximal exercise is presented in Appendix E.

Comparison of maximal oxygen uptake. The oxygen uptake response at maximal exercise for both respiratory valves is shown in Table 3. Sample size, means, standard deviations, and standard error of the means are presented.
A difference in mean values of 17.27 ml/kg/min was observed, and a $t$ test was computed to determine if that difference was statistically significant. With ten degrees of freedom, a critical value of 2.23 or greater was necessary to reject the null hypothesis. The obtained $t$ value was 2.62, thus indicating a significant difference in max $VO_2$ between the valves ($p < .05$). The Speak Easy measured oxygen uptake 24 percent lower than the Modified Otis-McKerrow.

Comparison of maximal heart rate. Descriptive data for maximal heart rate is presented in Table 4.

Table 3
Oxygen Uptake Response at Maximal Exercise

<table>
<thead>
<tr>
<th>Valve</th>
<th>n</th>
<th>$\bar{X}$</th>
<th>$\pm$ SD</th>
<th>$\pm$ SE</th>
<th>$t$ obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mod. Otis-McKerrow</td>
<td>11</td>
<td>70.89</td>
<td>8.05</td>
<td>2.43</td>
<td>2.62*</td>
</tr>
<tr>
<td>Speak Easy</td>
<td>11</td>
<td>53.62</td>
<td>17.76</td>
<td>5.36</td>
<td></td>
</tr>
</tbody>
</table>

$p < .05$

Table 4
Heart Rate Response at Maximal Exercise

<table>
<thead>
<tr>
<th>Valve</th>
<th>n</th>
<th>$\bar{X}$</th>
<th>$\pm$ SD</th>
<th>$\pm$ SE</th>
<th>$t$ obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mod. Otis-McKerrow</td>
<td>11</td>
<td>179.27</td>
<td>6.63</td>
<td>2.00</td>
<td>.51</td>
</tr>
<tr>
<td>Speak Easy</td>
<td>11</td>
<td>178.64</td>
<td>6.52</td>
<td>1.96</td>
<td></td>
</tr>
</tbody>
</table>
A difference in mean values of .63 beats/min was observed. The critical $t$, with ten degrees of freedom, was 2.23. The obtained $t$ value was only .51, therefore, the difference between the valves with respect to maximal heart rate was not significant at the .05 level of confidence.

Comparison of selected variables at maximal exercise. Eight other variables were measured including $V_E$, $V_O_2$, $V_C_O_2$, RQ, respiratory rate, blood pressures, and test duration. A descriptive summary is given in Table 5.

Table 5
Selected Cardiorespiratory Responses at Maximal Exercise

<table>
<thead>
<tr>
<th>Response</th>
<th>Valve</th>
<th>Otis-McKerrow</th>
<th>Speak Easy</th>
<th>$\bar{x}$</th>
<th>± SD</th>
<th>± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_E$ (l/min, BTPS)</td>
<td>Otis-McKerrow</td>
<td>143.24</td>
<td>14.57</td>
<td>4.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>116.05</td>
<td>12.03</td>
<td>3.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_O_2$ (l/min, STPD)</td>
<td>Otis-McKerrow</td>
<td>4.90</td>
<td>.60</td>
<td>.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>4.08</td>
<td>.45</td>
<td>.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_C_O_2$ (l/min, STPD)</td>
<td>Otis-McKerrow</td>
<td>4.64</td>
<td>.53</td>
<td>.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>4.00</td>
<td>.52</td>
<td>.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ</td>
<td>Otis-McKerrow</td>
<td>.96</td>
<td>.78</td>
<td>.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>1.01</td>
<td>.49</td>
<td>.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory Rate (breaths/min)</td>
<td>Otis-McKerrow</td>
<td>48.31</td>
<td>5.06</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>47.63</td>
<td>5.98</td>
<td>1.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic Blood Pressure (mmHg)</td>
<td>Otis-McKerrow</td>
<td>182.55</td>
<td>10.20</td>
<td>3.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>185.09</td>
<td>15.53</td>
<td>4.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diastolic Blood Pressure (mmHg)</td>
<td>Otis-McKerrow</td>
<td>79.82</td>
<td>7.77</td>
<td>2.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>75.64</td>
<td>10.27</td>
<td>3.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Duration (min)</td>
<td>Otis-McKerrow</td>
<td>8.75</td>
<td>.77</td>
<td>.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speak Easy</td>
<td>8.55</td>
<td>1.23</td>
<td>.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A remarkable difference in mean values occurred between values for 
$V_e$ (27.19 l/min) at maximal exercise. This represents a decrement of
19 percent when utilizing the Speak Easy mask. Because of this result,
a post hoc $t$ test was computed to determine whether that difference
would be significant at the .05 level of confidence. The $t$ obtained
was 8.73, greatly surpassing the 2.23 critical value (based on ten
degrees of freedom). Mean values for the remaining variables do not
warrant further comment at this point.

**Post Hoc Results**

A Randomized Block Factorial analysis of variance involving two
factors (valve and duration), with subjects repeated (Kirk, 1968) was
incorporated into the statistical analysis of the study. The analysis
of variance was computed for oxygen uptake, minute ventilation, and
heart rate. Only those stages completed by all eleven subjects (3, 5,
and 7 minutes) were included in the analysis. Provided the analysis of
variance proved significant (for the valve factor) and that no interaction
existed between the valve and duration factors, the Tukey Honestly
Significant Difference procedure for multiple comparisons was employed
to determine at what point the group means became significantly different.

**Analysis of variance of oxygen uptake.** The analysis of variance,
as described earlier, was computed on a post hoc basis for oxygen
uptake (ml/kg/min). The ANOVA summary table is presented in Table 6.
Table 6
Analysis of Variance of Oxygen Uptake During Exercise

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>914.46</td>
<td>10</td>
<td>91.25</td>
<td>2.85*</td>
</tr>
<tr>
<td>Valve</td>
<td>802.21</td>
<td>1</td>
<td>802.21</td>
<td>25.05*</td>
</tr>
<tr>
<td>Duration</td>
<td>781.83</td>
<td>2</td>
<td>390.92</td>
<td>12.21*</td>
</tr>
<tr>
<td>V X D</td>
<td>99.71</td>
<td>2</td>
<td>49.86</td>
<td>1.56</td>
</tr>
<tr>
<td>Residual</td>
<td>1690.90</td>
<td>50</td>
<td>32.02</td>
<td></td>
</tr>
</tbody>
</table>

Note. Reflects only data through stage three (7 min).

*p < .05

Subject, valve, and duration all exhibit F values in excess of their respective critical values (p < .05). Subject and duration effects were significant due to the inherent variability between subjects and the linear nature of the variables measured, respectively. No further comment will be made on those main effects. The main effect for the valves was found to be significant at the .05 level of confidence. Since there was no interaction observed between the valve and duration factors, it can be assumed that the significant differences between the valves was not duration-dependent, but a difference between the valves themselves.

The Tukey Honestly Significant Difference procedure for multiple comparisons was computed in order to define at which stage the significant difference between valves occurred. Comparisons were made between end...
of stage one (3 min) and end of stage two (5 min) and between end of stage two and end of stage three (7 min). The differences were found to be significantly different only between the three and five minute durations ($p < .05$). The $q$ obtained was 3.75, and that exceeded the critical value of 3.40 ($q < 3.60$). The obtained $q$ for differences between the five and seven minute durations was 3.23, not enough to reject the null hypothesis.

Mean oxygen uptake values at the end of each stage in the Modified Astrand treadmill protocol were plotted for descriptive analysis (see Figure 2).
Oxygen uptake with the Modified Otis-McKerrow valve rises linearly from the end of stage one (3 min) through the end of stage three (7 min). Conversely, the Speak Easy mask appears to plateau slightly between the five and seven minute duration. Although not statistically significant, the differences between the two valves is more apparent at the seven minute duration. A mean difference of 10.30 ml/kg/min exists at that point as compared to 6.18 ml/kg/min at the five minute mark. From this illustration, it appears that the differences in oxygen uptake between the valves increases with increasing workloads, up to maximal exercise.

Analysis of variance of heart rate. The analysis of variance for heart rates during exercise is presented in Table 7.

Table 7
Analysis of Variance of Heart Rate During Exercise

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>5806.61</td>
<td>10</td>
<td>580.66</td>
<td>32.59*</td>
</tr>
<tr>
<td>Valve</td>
<td>4.38</td>
<td>1</td>
<td>4.38</td>
<td>.25</td>
</tr>
<tr>
<td>Duration</td>
<td>3839.39</td>
<td>2</td>
<td>1919.70</td>
<td>107.75*</td>
</tr>
<tr>
<td>V x D</td>
<td>45.21</td>
<td>2</td>
<td>22.61</td>
<td>2.65</td>
</tr>
<tr>
<td>Residual</td>
<td>890.85</td>
<td>50</td>
<td>17.82</td>
<td></td>
</tr>
</tbody>
</table>

Note. Reflects only data through stage three (7 min).

*p < .05

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As expected, subjects and duration were found to be significant $(p < .05)$, but will not be treated or discussed further. The difference in measured heart rates between the valves was not significant at the .05 level of confidence. Multiple comparisons were not warranted, but the mean values were plotted as shown in Figure 3.

![Graph showing mean heart rate response during exercise](image)

**Figure 3. Mean Heart Rate Response During Exercise**

At the end of stage one (3 min), a small difference was observed. Heart rate was higher (2.82 beats/min) with the Modified Otis-McKerrow valve. By the end of stage two (5 min), the heart rate was slightly
higher (1.0 beats/min) with the Speak Easy mask. At the seven minute point, the valves produced nearly equal heart rates. The trend in this plot would suggest that, with increasing workloads up to maximal exercise, heart rate is not effected by the valves under comparison.

Analysis of variance of minute ventilation. The highly significant difference found in $V_e$ warranted further investigation as well. The ANOVA was computed and is displayed in Table 8.

Table 8
Analysis of Variance of Minute Ventilation During Exercise

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>5028.60</td>
<td>10</td>
<td>502.86</td>
<td>9.14*</td>
</tr>
<tr>
<td>Valve</td>
<td>3280.37</td>
<td>1</td>
<td>3280.37</td>
<td>59.65*</td>
</tr>
<tr>
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<td>54.99</td>
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Note. Reflects only data through stage three (7 min).

$p < .05$

Again, subject and duration factors were significant. More importantly, the $F$ obtained for the difference in the valve factor was highly significant ($p < .05$). Since no interaction occurred between duration and valve factors, the Tukey Honestly Significant Difference procedure was again utilized to establish where the mean values deviated significantly. The $q$ obtained for the comparison between the three and
five minute and between the five and seven minute durations were 7.56 and 11.27, respectively. Both of these values exceed the critical value of 3.40 (95% CI 3.60). It can be concluded that mean differences in \( V_E \) between the valves were significant throughout the submaximal levels of exercise.

The mean values for minute ventilation during exercise were plotted and are presented in Figure 4.

![Figure 4. Mean Minute Ventilation Response During Exercise](image)
It appears that with increasing duration (workload), the differences in measured values for minute ventilation are increased. Mean differences between the valves at three, five, and seven minute durations were 9.42, 12.81, and 20.06 l/min, respectively.

**Discussion**

Based on the results of this study, the Speak Easy mask produces questionable data in two key responses. Both maximal and submaximal oxygen uptake and minute ventilation were found to be significantly different from those same measurements acquired by the Modified Otis-McKerrow valve. Maximal heart rate, however, was not significantly different between the two valves. A further discussion of these findings follows.

**External airway resistance.** One possible explanation for the decreases in oxygen uptake and minute ventilation obtained from the Speak Easy mask could be external airway resistance. The results of this study closely agree with the data presented by Silverman et al., (1951). In their study, increased resistance created a significant reduction in oxygen uptake. In addition, minute ventilation was 20 percent as compared to 19 percent found in this study. Craig et al. (1970) found that oxygen uptake was significantly impaired and that time to exhaustion was decreased with added external resistance. In a similar report, Dressendorfer et al. (1977) found significant decreases in minute ventilation, oxygen uptake, heart rate, and endurance time. In a study similar to this study, Hermansen et al. (1972)
compared a conventional valve with a mask. They found a significant decrement in oxygen uptake during maximal work with the mask. In addition, minute ventilation was also reduced at peak flow rates. Minute ventilation was lower with the mask throughout exercise, although not statistically significant. The same maximal heart rate was observed for both valves, with the mask eliciting a slightly higher heart rate at submaximal workloads.

Several studies have reported decreases in heart rate, oxygen uptake, and minute ventilation (VanHuss and Heusner, 1965; Cerretelli et al., 1969; and Flook and Kelman, 1973).

Numerous investigators have provided explanations for the impaired responses due to external airflow resistance. Demedts and Anthonisen (1973) suggested that the amount of exercise limitation created by a given resistance depended, first, on the ventilatory limitations produced by the resistance, and given that ventilatory limitation, on CO₂ responsiveness of the individual. Other researchers (Cerretelli et al., 1969; Craig et al., 1970; Flook and Kelman, 1973; and Dressendorfer et al., 1977) have provided similar explanations.

Freedman and Campbell (1970) found that different types of external mechanical resistances produce significantly different patterns of ventilatory response. They also expressed the opinion that the inability to tolerate resistance cannot be explained in terms of the observed changes of ventilation, pattern of breathing, or inspiratory force. They concluded that the ventilatory response to added resistance must
be regarded as a summation of various factors, such as the role of the respiratory muscles in providing intrinsic stability and reflexes that effect those muscles.

Gothe and Cheniack (1980) suggested that increases in inspiratory activity observed with both inspiratory and expiratory resistance implies that input from higher brain centers is necessary for the increased responses.

Widdicombe (1963) discussed the Hering-Breuner Inflation reflex. This reflex is thought to be mediated by pulmonary stretch receptors which inhibit spontaneous diaphragmatic contractions when the lungs are inflated. His review of related studies showed that there is an optimal breathing frequency and corresponding tidal volume at which the mechanical work of breathing is minimal. Deviation from this optimal frequency is uneconomic in terms of work on the respiratory system. It has been suggested that the Hering-Breuner Inflation reflex may be the agent for eliciting changes in the breathing patterns in response to alterations in lung mechanical conditions. Irritant and pulmonary vascular reflexes were discussed and shown to produce bradycardia in some instances.

Altose et al. (1978) found that successive amounts of resistance increased inspiratory activity. The level of inspiratory activity remained elevated for a single breath following the removal of the added resistance. Their results suggest that non-chemically mediated respiratory compensation (reflexes) in conscious individuals develops rapidly and is important in maintaining ventilation when breathing is encumbered.

At this point, it is questionable as to the magnitude with which external airway resistance can be used as an explanation for the results
of this study. Andersen et al. (1971) recommended that respiratory valves used in the collection of expired gas entail less than 5 cm H₂O at a flow rate of 300 l/min. In this study, the Modified Otis-McKerrow and Speak Easy mask were measured at 11.9 and 36.3 mm H₂O (1.19 and 3.63 cm), respectively, for inspiratory resistances at a mean flow rate of approximately 80.2 l/min. Although the difference in inspiratory resistances provided some of the rationale for the study, their values are within the recommended standards and well below many of the added resistances utilized in the previously reviewed studies.

One response effected by meaningful increases in external airflow resistance and reported by most of the investigations (Demedts and Anthonisen, 1973; VanHuss and Heusner, 1965; Cerretelli et al., 1969; Dressendorfer et al., 1977; and Craig et al., 1970). In the present study, exercise duration did not appear to be effected by the type of valve used (see Table 5). Decreases in heart rate with increased resistance has also been reported (Craig et al., 1970; Dressendorfer et al., 1977; VanHuss and Heusner, 1965; and Cerretelli et al., 1969). As reported in the results of this study, heart rate is virtually unchanged by type of valve. In fact, maximal heart rate values were nearly identical. In view of these inconsistent responses, it appears as though external airflow resistance cannot provide an adequate explanation for the results.

Dead space. Regardless of the amount of dead space, numerous studies (Bouhuys et al., 1972; Jones et al., 1971; Bartlett et al., 1972; Ward and Whipp, 1980; and Bolen, 1981) reported that added dead
space did not alter oxygen uptake or heart rate. Minute ventilation was effected, increasing, rather than decreasing with increased dead space. It seems unlikely that dead space would provide a solution for the obtained results, either. In this study, both valves contained comparable amounts of dead space, thus neutralizing the effect on the results.

Leakage. Lenox and Koegel (1973) were the only investigators to report leakage quantitatively. Others (Flook and Kelman, 1973; Andersen et al., 1971) have indirectly addressed the problem.

Wilson et al. (1980) compared the Speak Easy mask with a Daniels and a Lloyds valve. They found no significant differences in their obtained results. It was strongly emphasized that no leakage occurred during pulmonary function and exercise stress testing procedures with the Speak Easy mask.

In this study, seven subjects reported that they experienced leakage during the test, especially around the bridge of the nose. The leakage appeared to increase (become more noticeable) with additional workloads.

Another factor to consider involves the mode of testing. The subjects in this study were tested on a motor-driven treadmill at workloads requiring a fast running pace (8.5 mph). Wilson et al. (1980) utilized bicycle ergometry that would involve only slight movements of the head and valve. It would be logical to assume that the potential for leakage would be far greater when taking into consideration the bouncing effect of the running protocol.
Flow rates measured in this study represent a higher volume (20 percent higher) than the values attained in the study by Wilson et al. (1980). A greater volume expired per minute could possibly create a greater potential for leakage around the mask seal.

The decreases in both oxygen uptake and minute ventilation reported in this study could be explained, in part, by the leakage factor. The loss of expired air by the Speak Easy mask would manifest itself in a decreased value for that measurement. It would also decrease the oxygen uptake value due to the loss of expired volumes of air. In addition to those effects, leakage from the mask would decrease the volume of expired air traveling across the expiratory valve flap, therefore, minimizing the airflow resistance the subject might encounter. By minimizing the resistance across the valve flap, differences that might have been attributed to external airflow resistance would be less noticeable.

Although the direct measurement of leakage was beyond the scope of this study, factors such as subject feedback, testing mode (treadmill), high ventilation volumes, and possible decreased resistance would indicate that, perhaps, leakage does represent a plausible explanation for the results obtained from this study.

These findings seriously question the integrity of the Speak Easy mask, especially in subjects with high functional capacities and for treadmill testing protocols. A review of Figures 2 and 4 show that with increased workloads, the Speak Easy was unable to keep pace with the Modified Otis-McKerrow valve. However, the differences for oxygen uptake and minute ventilation at the end of stage one (3 min) suggests
that, for lower workloads and flow rates, the Speak Easy may be capable of providing reasonable data. Indications for the use of the Speak Easy may be found in low level testing of both cardiac and pulmonary patients. Bicycle ergometry testing with low level protocols may lend itself to the use of the Speak Easy as well.

As for the collection of expired air in the stress testing of athletes, these results would suggest that a standard valve with a combination of low dead space, resistance, and leakage be utilized to ensure the accuracy of the collected data.
CHAPTER V
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this investigation was to identify the differences in selected cardiorespiratory responses between the Modified Otis-McKerrow valve and the Speak Easy mask. It was the intent of this study to highlight those undesirable characteristics responsible for the differences measured. This chapter includes: (a) a Summary of the results, (b) Conclusions, and (c) Recommendations.

Summary

Following graded exercise tests, the maximal oxygen uptakes of eleven distance runners from Western Michigan University's track team were compared. A t test revealed that there was a significant difference (p < .05) between the two valves. The max $VO_2$ was 24 percent lower with the Speak Easy mask. A post hoc analysis of variance was computed to define if differences occurred at submaximal levels during the test. The obtained $F$ was significant (p < .05) as well. A multiple comparison procedure was utilized to determine between which stages in the treadmill protocol the differences occurred. A significant difference was found only between the first and second stage. Differences between stage two and three were large, but not statistically significant.

Maximal heart rate was compared with a t test. The obtained $t$ was not significant (p > .05). An analysis of variance was calculated to investigate the possibilities of a significant difference occurring.
before the maximal level. There was no significant difference at the .05 level of confidence.

Minute ventilation was analyzed after the large difference in mean values was observed. A t test revealed a significant difference ($p < .05$), with the Speak Easy mask measuring ventilation 19 percent lower. The analysis of variance was also found to be significant ($p < .05$). Multiple comparisons showed that significant differences occurred between both stage one and stage two and between stage two and stage three.

Descriptive analysis was made for oxygen uptake (l/min), carbon dioxide production, respiratory exchange ratio, respiratory rate, systolic and diastolic blood pressure, and test duration. There were no remarkable differences found in those measures, therefore, no further treatment of the data was conducted.

**Conclusions**

The conclusions of this study are presented as follows:

1. It is apparent from the results of this study that the Speak Easy mask produced significant differences in measured oxygen uptake and minute ventilation. The values for oxygen uptake and minute ventilation at maximal exercise were much lower for the Speak Easy mask, representing a 24 and 19 percent decrease, respectively.

2. From the data collected in this study, it appears that heart rate for both maximal and submaximal exercise was not significantly altered by the type of valve used. In addition, measurements of oxygen
uptake (l/min), carbon dioxide production, respiratory exchange ratio, respiratory rate, systolic and diastolic blood pressure, and test duration were not markedly effected by type of valve, either.

3. In light of the results of this study, and the review of related investigations, it would be plausible to attribute most of the significant differences to valve leakage.

**Recommendations**

This section contains recommendations for further study. Suggestions for the use of respiratory valves in the collection of expired air are also presented.

Further studies are recommended in which larger and more varied subject populations are tested under a wider range of testing protocols with the Speak Easy mask. Such research may define the appropriate application of the Speak Easy mask with respect to exercise testing.

Additional research is needed in which quantitative measures can be made to objectively assess the amount of leakage, if any, occurring with the Speak Easy mask. Other respiratory valve apparatus should be tested in the same manner. Results of such research may aid in the development of improvements that would make mask-type devices more acceptable for gas collection procedures.

It is recommended that the use of the Speak Easy mask be limited until further studies or intrinsic improvements are made that would support its use in gas collection procedures. One improvement that could be made in the Speak Easy mask would be the use of additional
tension straps, thus providing a better seal around the face. That modification could conceivably reduce the amount of leakage.

A set of industry standards for the development and manufacture of exercise testing and gas collection equipment poses a final suggestion. Acceptance and compliance to well documented standards would ensure that new as well as existing devices are capable of providing quality data.
APPENDICES
APPENDIX A

Modified Astrand Protocol

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*Note.* Protocol based on Pollack (1976). The speed could be adjusted up to a maximum of 8.5 mph based on the ability of the subjects.
APPENDIX B

Instructions for Stress Testing

1.) On the day of your scheduled test, bring the following items: towel, soap/shampoo, running shorts, jock, socks, and training flats. You will not need a T-shirt.

2.) On the day of your scheduled stress test, do not engage in any speed workouts. Since the tests will be conducted in the early evening, you may run up to six (6) miles at an easy pace. If you decide to go out for a run, do so in the morning, BEFORE noon.

3.) Do not eat any less than 2 hours before your scheduled stress test. You may, however, drink water.

4.) When you arrive at the Cardiac Rehabilitation Institute, check in with the receptionist and sign in on the patient register at the reception counter.

5.) Most importantly, take note as to your daily habits for the first testing date. Try to duplicate everything (i.e. what you eat, how much you run, amount of sleep the night before, etc.) on the second testing date as you did on the first testing date.

6.) A coin toss will be utilized to determine which valve you will use on the first test. Whichever valve is not used in the first test, will be used in the second test, exactly one week later at the same time.
APPENDIX C

Informed Consent Form

1. Explanation of the Graded Exercise Test
   You will perform a graded exercise test on a motor-driven treadmill. The work levels will begin at a level you can easily accomplish and will be advanced in stages, depending on your work capacity. We may stop the test at any time because of abnormal responses to the exercise or you may stop when you are too fatigued to continue.

2. Risks and Discomforts
   There exists the possibility of certain changes during the test. They include abnormal blood pressure, fainting, disorders of heart beat, and very rare instances of heart attack. Efforts will be made to minimize them by the preliminary exam and by observations during testing. Emergency equipment and trained personnel are available to deal with unusual situations which may arise.

3. Benefits to be Expected
   The results obtained from the exercise test may assist in evaluating your current functional capacity and may also provide information for establishing a training program to improve your level of fitness.

4. Inquiries
   Any questions about the procedures used in the graded exercise test or in the determination of functional capacity are welcome. If you have any questions, please ask us.

5. Freedom of Consent
   Permission for you to perform this graded exercise test is voluntary. You are free to deny consent if you so desire.

   I have read this form and I understand the test procedures that I will perform and I consent to participate in this test. I also release all data and information for publication and/or presentation without my name attached to it.

   ________________________________
   Signature of Subject

   ________________________________
   Date

   ________________________________
   Witness
### APPENDIX D

**Raw Data Collection Form**

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| 10         |            |       |    |    |            |    |           |             |                |             |    |
# APPENDIX E

Subject Data at Maximal Exercise

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<th>VO₂ (ml/kg/min)</th>
<th>VE</th>
<th>VO₂</th>
<th>VCO₂</th>
<th>RQ</th>
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