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Abstract

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Oxygen and Carbon Dioxide Levels During Qualitative Respirator Fit Testing

A thesis submitted to the

Division of Research and Advanced Studies
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of the College of Medicine

2004

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Abstract

Approved Occupational Safety and Health Administration qualitative respirator fit test methods require the use of a test hood about the subject's head and shoulders. Workers fit tested by this method have commented on the discomfort of being inside the test enclosure. This study was designed to quantify some parameters that might lead to these types of comments. For this study, subjects performed a series of four respirator fit tests. A quantitative and a qualitative fit test were performed with a full facepiece respirator. Then a quantitative and a qualitative fit test were performed with an N95 filtering facepiece respirator. Parameters measured include: subjects height, weight, and age, oxygen and carbon dioxide levels, air temperature, heart rate, arterial oxygen saturation, and Borg Ratio Scale value on breathing exertion. Carbon dioxide levels are significantly higher and oxygen levels are significantly lower in the respirator when the test hood is used during the qualitative fit test. The temperature inside the test hood rose an average 7.5°F in the course of the qualitative fit test of the N95 filtering facepiece device. These stressors are not present during a quantitative respirator fit test. Professionals conducting respirator fit tests should be aware of the physiological burdens that may occur during the qualitative respirator fit test. Some groups may be especially sensitive to this test such as the elderly, pregnant women, persons with pulmonary and/or cardiac disease, or persons with psychological disorders such as anxiety, panic disorders, or claustrophobia.

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1.0 INTRODUCTION

When conducting required Occupational Safety and Health Administration (OSHA) respirator qualitative fit tests (QLFT),[1] workers often comment the air inside the test hood feels hot and uncomfortable. This leads to the questions: What are the actual environmental conditions inside the test hood? and What influences them?

OSHA has approved quantitative fit test (QNFT) and QLFT test methods for fit testing respirators.[1] OSHA permits a QLFT to be used to fit test full facepiece respirators when worn with a positive pressure device, such as a self-contained breathing apparatus. One type of QNFT allows the use of an ambient aerosol condensation nuclei counter (Portacount™).[1] The Portacount™ measures particles in the ambient air and also inside the respirator as the test subject wears the respirator. The Portacount™ software then calculates an overall fit factor based on the ratio of the outside concentration to inside concentration of the respirator.[2] The QLFT is another way to fit test respirators. The saccharin and bitrex™ solution aerosol protocol utilize a test hood about a person's head and shoulders while he/she wear a respirator.[1] The challenge agents are then sprayed into the test hood and the worker subjectively indicates whether he/she can detect the challenge agent.

The OSHA Permissible Exposure Limit[3] (PEL) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV)[4] for carbon dioxide (CO_2) is 5000 ppm (0.5%). The ACGIH TLV is recommended to minimize the potential for asphyxiation and undue metabolic stress.[5] The ACGIH short term exposure limit (STEL) for CO_2 is 30,000 ppm (3.0%)[4], based on the short term high CO_2 exposure studies that produced increased pulmonary ventilation rates.[5] The National Institute of Safety and Health (NIOSH) immediately dangerous to life and health (IDLH) value for CO_2 is 40,000 ppm (4.0%), for up to 30 minutes for egress.[6,7]

Typical room air consists of 20.9% oxygen (O_2), 79% nitrogen, and 0.1% CO_2, water vapor, and other inert gases.[8] The concentration of CO_2 in alveolar air is 5%.[8] CO_2 is formed by cellular respiration and is removed by pulmonary ventilation.[8] If the concentration of the inspired CO_2 is increased, it will alter the normal diffusion gradients of the alveolar blood.[8] An increase in alveolar CO_2 will result in hypercapnia (elevated levels of CO_2 in the blood result from inadequate ventilation or from massive mismatches between ventilation and perfusion of the blood) and systemic acidosis.[8] The effects of inhaled CO_2 is several fold.[9] First, the stimulation of respiration adds to the burden of the work of breathing, and could decrease the ability to produce physical work if the work was performed at close to the maximum level.[9] Second, CO_2 directly causes a feeling of discomfort and unease, and may cause sufficient anxiety to affect work performance.[9] Third, CO_2 has local vasodilator effects, and may affect the ability to work by shunting blood from other working muscles.[9]

CO_2 is the principal regulator of respiration, acid-base balance, and behavioral state arousal in humans.[10] In normal individuals, hypercapnia is mildly to moderately anxiogenic, but individuals with panic disorders are susceptible to more intense anxiety or even panic attacks.[10] This has been demonstrated from prolonged exposure to low levels of CO_2.[10] Unconsciousness and death can occur as the concentration of inhaled CO_2 reaches 10%.[8] Other symptoms reported at exposures of 7.5% CO_2 for 15 minutes were dyspnea, headache, restlessness, visual color distortions, vertigo, sweating, numbness, irritability, and mental disorientation.(11) Cardiac rhythm changes were noted when 6% CO_2 was administered for 6-8 minutes.(11) Exposure to CO_2 at 5% for 30 minutes can cause decreased vascular resistance and increased renal blood flow; with continuous exposure to 3% CO_2 the only observed changes are limited to renal and respiratory compensatory mechanisms without any apparent adverse symptoms.(11) Acclimatization, or the development of tolerance to CO_2 has been shown consistently.(11) Diminished respiratory response to a subsequent challenge of 5% CO_2 has been demonstrated after prolonged exposures at CO_2 concentrations of 1.5-3%.(11) The increased ventilatory response produced by chronic CO_2 exposures returns to normal after 2-3 days of exposure at 1.5 to 3%.(11) The body compensates to the exposure by increasing respiratory efficiency evidenced by improved O_2 intake and CO_2 excretion.(11)

OSHA defines O_2 deficiency as an atmosphere that contains less than 19.5% O_2 by volume and O_2 enriched as any atmosphere that contains more than 22% O_2 by volume.(12) A minimum value of 19.5% O_2 has been widely accepted as the criterion for identifying a space as O_2 deficient.(13) An O_2 level of 16% at standard temperature and pressure (STP) can result in increased heart rate, increased breathing rate, some decrease in coordination, increased breathing volume, impaired attention, and impaired thought processes.(13) At concentrations less than 14% at STP, health effects include: abnormal fatigue on exertion, emotional upset, faulty coordination, and impaired judgment.(13) A 10% O_2 content at STP may cause nausea, vomiting, lethargy, and inability to perform vigorous movements, possible unconsciousness, followed by death.(13) At concentrations less than 4% at STP unconsciousness within 1 or 2 breaths followed by death may occur.(13) The human body responds to the alveolar partial pressure of O_2 rather than the percentage of O_2 in respired air.[13] Therefore a substantial lack of agreement exists as to what actually constitutes an O_2 deficient IDLH atmosphere.[13]

Respiratory inspiratory resistance induces hypoventilation with lower minute volumes and lower O_2 consumption values at higher resistances.[14, 15] Average O_2 consumption rates and minute ventilation also decrease linearly with increased expiratory resistances, indicating that increases in expiratory resistance result in a considerable level of hypoventilation.[16] Hypoventilation while wearing respirators causes higher amounts of blood lactate.[15] The respirator wearer decreases O_2 consumption relative to the unmasked person.[15] The result is that body metabolism is more anaerobic and blood lactate builds up more quickly for the respirator wearer.[15] In order to supply the O_2 requirements of the body, a hypoventilating person must extract more O_2 from each breath.[15] Respiration rates with the full facepiece respirator are lower than without.[15] Inhalation times are longer due to increased inhalation resistance.[15] It appears, therefore that the inhalation resistance leads to hypoventilation, which leads to higher CO_2 and lower O_2 levels in exhaled air.[15] Metabolic processes of the respirator wearer do not change when a respirator is worn, but the respirator adds a respiratory burden due largely to increased breathing resistance, for which compensatory adjustments are not complete.[15] Thus anaerobic metabolism occurs at a higher rate, and maximum O_2 deficit is reached sooner with the respirator than without.[15] It has been shown that exercise performance time was decreased due to hypoventilation, or the inability of ventilation to keep pace with O_2 consumption.[17] In another study, it was shown that respirator exhalation resistances are better tolerated than inhalation resistances for individuals engaged in relatively hard physical activities.[16]

A variable that may influence the amount of CO_2 build up inside of the test hood is the rate a person generates CO_2. Every person has a respiratory quotient (RQ) defined as CO_2 production divided by O_2 consumption.(18) The RQ can be affected by diet and body composition. The RQ is significantly higher in lean compared to obese subjects.(18) RQ increases significantly after a carbohydrate-rich meal and decreases after a fat-rich meal in both lean and obese study groups.(18) Therefore, someone who is in good physical condition and burning fats will have a lower value of CO_2 in exhaled air than a person that is burning primarily carbohydrates. One way to quantify a subject is to measure their weight and height. Another way to use both of these values is with Body Mass Index (BMI). The Centers for Disease Control (CDC) has defined BMI as a way to compare sizes of one person to another person or to an index(19). BMI is a tool for indicating weight status in adults.(19) BMI *correlates* with body fat.(19) Two people can have the same BMI, but a different percent body fat.(19) The relation between fatness and BMI differs with age and gender.(19) For example, women are more likely to have a higher percent of body fat than men for the same BMI.(19) On average, older people may have more body fat than younger adults with the same BMI.(19)

O_2 consumption and CO_2 production are elevated at rest during pregnancy.(20) Increased O_2 utilization together with decreased O_2 reserves make pregnant women particularly susceptible to hypoxia during hypoventilation or apnea.(21) In some pregnant women, a higher sensitivity to CO_2 and hypoxia may induce excessive ventilation upon metabolic demand, which would contribute to dyspnea.(22) Dyspnea is a common and normal physiologic response during pregnancy, occurring in 60 to 70% of pregnant women.(22)

2.0 MATERIALS AND METHODS

Twenty subjects (10 male and 10 female) accomplished a series of four respirator fit tests. A QNFT and a QLFT were conducted with a Scott O-Vista full facepiece respirator and an MSA Affinity Pro N95 filtering facepiece respirator (Note: the N95 did not have any inhalation or exhalation valves).

2.1 Subject Testing Procedure

Prior to testing, each subject was medically cleared through the process of completing a Respirator Medical Evaluation Questionnaire. The subject reviewed and signed a written consent form approved by the University of Cincinnati Institutional Review Board before testing started. On the day of testing, measured height and weight, demographic data and smoking status were collected. The room CO_2 and O_2 concentrations were measured with a GEM-500 infrared gas analyzer (Landtec Landfill Control Technologies, Commerce, CA). The analyzer was calibrated using certified 10% CO_2 and 20.9% O_2 gas (Gasco Affiliates, Sarasota, FL). The manufacturer's literature listed an accuracy of ±0.3% for CO_2 and ±1.0% for O_2. Room temperature was recorded with a General Electric Wireless digital indoor/outdoor thermometer, model GE5805WS5, with an accuracy of ±1.8° Fahrenheit (F). An initial value of breathing exertion was obtained using the Borg Ratio Scale.[(23)] Heart rate and arterial O_2 saturation were ascertained with an N200 Pulse Oximeter and a DS-100A Durasensor (Nellcor Corp., Hayward, CA). This meter has an accuracy of saturation without motion of 70 to 100% ±2 digits and pulse rate without motion of 20 to 250 bpm ±3 digits. The sensor was always attached to the subject's right index finger with the wire adjacent to the subject's fingernail per manufacturer's instructions. Values of CO_2 and O_2 were obtained during normal breathing, one-inch in front of the subject's mouth.

A full facepiece respirator was selected for testing with a Scott fit test adapter and high efficiency (HE) filters. The subject was instructed on the proper procedure for a respirator user seal check. The subject donned this respirator and conducted user seal checks. In all cases, user seal checks were satisfactory before fit testing proceeded and were repeated every time a respirator was donned. An IBM ThinkPad Pentium laptop computer with TSI software controlled the TSI Portacount™ Plus Model 8020A (TSI Inc., Shoreview, MN) during fit testing. Connectors were installed on the ends of the tube between the Portacount™, fit test adaptor, and gas analyzer.

A QNFT with the full facepiece respirator was conducted. The subject donned the respirator, completed user seal checks, then became comfortable wearing the respirator. The subject completed eight one- minute exercises consisting of normal breathing, deep breathing, turning the head side to side, moving the head up and down, talking, grimace, bending at the hips, and normal breathing while wearing the respirator connected to the Portacount™. Values of CO_2 and O_2 were recorded for the respirator 30 seconds after the end of the test. The value of 30 seconds was chosen to allow for adequate time for a sample to reach the analyzer and to reduce observer bias, such as recording only the highest value. The length of time the subject wore the respirator varied from 12 to 15 minutes for each fit test conducted. Values for heart rate, arterial O_2 saturation, and breathing exertion were recorded at the end of the fit test. The subject removed the respirator for at least one minute, then donned the same respirator in preparation for a QLFT with the test hood.

A test hood from a 3M Qualitative Fit Test Apparatus was placed over the head and resting on the subject's shoulders. The temperature sensor located inside the test hood on the anterior lower plastic rim was on the subject's right side. The QLFT was performed with the same full facepiece respirator. No challenge agents were used during this mock QLFT procedure. At least 30 seconds prior to the end of this fit test, the sampling hose was inserted into the test hood and placed next to a filter inlet of the respirator. When the last normal breathing maneuver was completed, the CO_2 and O_2 values for the test hood were recorded. Procedures and timing of gas sampling were identical during QNFT and QLFT. After thirty seconds elapsed, the CO_2 and O_2 levels were recorded inside the respirator. Values for heart rate, arterial O_2 saturation, breathing exertion, room temperature, and temperature inside the test hood were recorded at the end of the fit test. The subject removed the respirator and rested prior to the next phase of testing with a different style respirator (N95 filtering facepiece).

An N95 filtering facepiece respirator was selected and a probe was installed using a TSI Fit Test Probe Kit (P/N 8025-N95). A twelve-inch section of tubing was attached to this probe. The subject was asked to don the mask, tighten the straps, and perform a user seal check. A TSI N95 Companion Model 8095 was connected to the Portacount™ to conduct the QNFT. The Companion changed each exercise test length to 85 seconds. A QNFT was conducted and the measured parameters were recorded. The subject removed the filtering facepiece for at least one minute, then donned the same respirator for a comparison test while wearing a test hood during the QLFT.

A QLFT was performed with the N95 respirator and the measured parameters of CO_2, O_2 heart rate, arterial O_2 saturation, breathing exertion, room temperature, and temperature inside the test hood were recorded at the end of the fit test. The subject removed the respirator after testing was complete. At the end of the session, the subject was asked to report any health symptoms.

Since body mass can influence CO_2 levels, subjects height and weight were used to calculate body mass index (BMI).[(19)]

Data Analysis

A one-sample t-test was performed when comparing CO_2 levels in each respirator type with the STEL and O_2 levels in each respirator type with the O_2 deficient level. Hypothesis testing was performed using the two sample t-test assuming population variances are equal when comparing gas levels of each respirator type. A p value <0.05 was considered statistically significant. A regression analysis was conducted on the height, weight, BMI, and levels of CO_2 and O_2. The coefficient of determination, r^2, was used to determine if a correlation existed. The independent variables were height, weight, and BMI. The dependent variables were CO_2 and O_2.

3.0 RESULTS

Seventeen of twenty volunteer subjects were University of Cincinnati students from the Department of Environmental Health and three were from the community. All subjects passed medical clearance and had no facial hair. One subject was a smoker but had not smoked within 30 minutes of starting the fit tests. Instructions on donning a respirator were provided to subjects and all had worn a respirator at least one time prior to fit testing. Subject characteristics were as follows (mean ± standard deviation [SD] (range)): age, 30 ± 6.2 years (23 to 43); height, 67.25 ± 3.0 inches (62 to 72); weight, 176 ± 39.3 pounds (126 to 250); BMI, 27.2 ± 5.6 (20.3 to 38.9).

Fit Factors

Nineteen participants had fit factors exceeding the OSHA minimum of 500 for the full facepiece QNFT. One subject received an overall fit factor of 314 for the full facepiece QNFT, they received scores higher than 500 for all tests except the bending exercise which had a score of 49. The subject mentioned that the respirator slipped on their face when they bent over. During the N95 filtering facepiece QNFT, two subjects did not achieve the OSHA minimum passing score of 100. The non passing scores were 4.1 and 48.

Carbon Dioxide

Figure 3.1 illustrates the results of CO_2 levels present inside the respirator or test hood during fit testing. Average CO_2 levels by respirator type and fit test method are shown in table 3.1. The median levels of CO_2 were very close to the average levels.

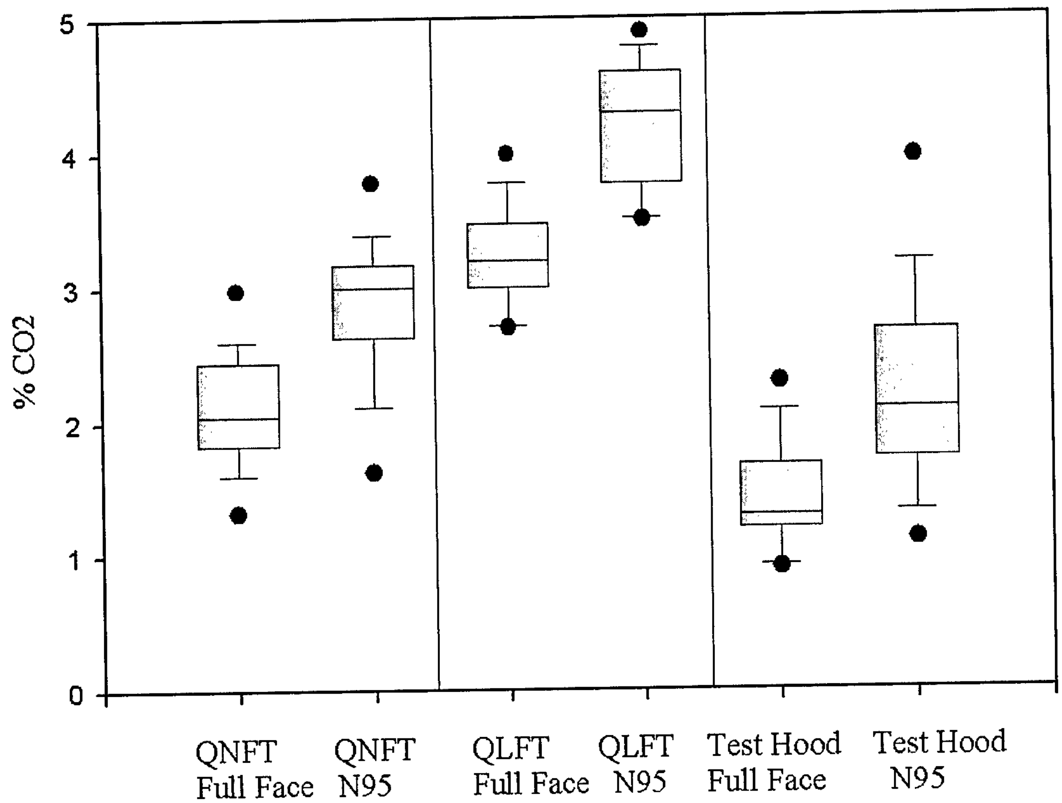

Figure 3.1 Percent CO_2 Levels Measured Inside the Respirator or Test Hood. The boxplot shows the following: horizontal lines from the bottom, 10th, 25th, 50th, 75th, 90th percentiles;

• - shows the range of data

Table 3.1 Mean and Standard Deviation of CO_2 Levels Inside the Respirator or Test Hood

		Mean (%)	SD (%)
QNFT (in mask)			
	Full Facepiece	2.1	0.4
	N95 Filtering Facepiece	2.8	0.5
QLFT (in mask)			
	Full Facepiece	3.2	0.4
	N95 Filtering Facepiece	4.2	0.4
Test Hood Level QLFT			
	Full Facepiece	1.4	0.4
	N95 Filtering Facepiece	2.2	0.7

A comparison of the mean CO_2 level inside the respirator during fit testing with the STEL was conducted and the results are presented in table 3.2. A value of 13 minutes was used to compute the time-weighted average with the STEL. A comparison was conducted on the CO_2 levels present in the two types of respirators. The mean level of CO_2 was significantly higher in the N95 filtering facepiece than the full facepiece respirator after the QNFT, QLFT, and inside the test hood ($p<0.0001$).

Table 3.2. Comparison of Mean CO_2 Level and the STEL (3.0%) During QNFT and QLFT

		Comparison	p value
Full Facepiece	QNFT	$CO_2 < STEL$	<0.0001
	QLFT	$CO_2 > STEL$	<0.01
N95 Filtering Facepiece	QNFT	$CO_2 < STEL$	<0.0001
	QLFT	$CO_2 > STEL$	<0.0001
Test Hood	QLFT Full Facepiece	$CO_2 < STEL$	<0.0001
	QLFT N95 Filtering Facepiece	$CO_2 < STEL$	<0.0001

Oxygen

Figure 3.2 illustrates the results of O_2 levels present inside the respirator or test hood during fit testing. Average O_2 levels by respirator type and fit test are shown in table 3.3. The median levels of O_2 were very close to the average levels.

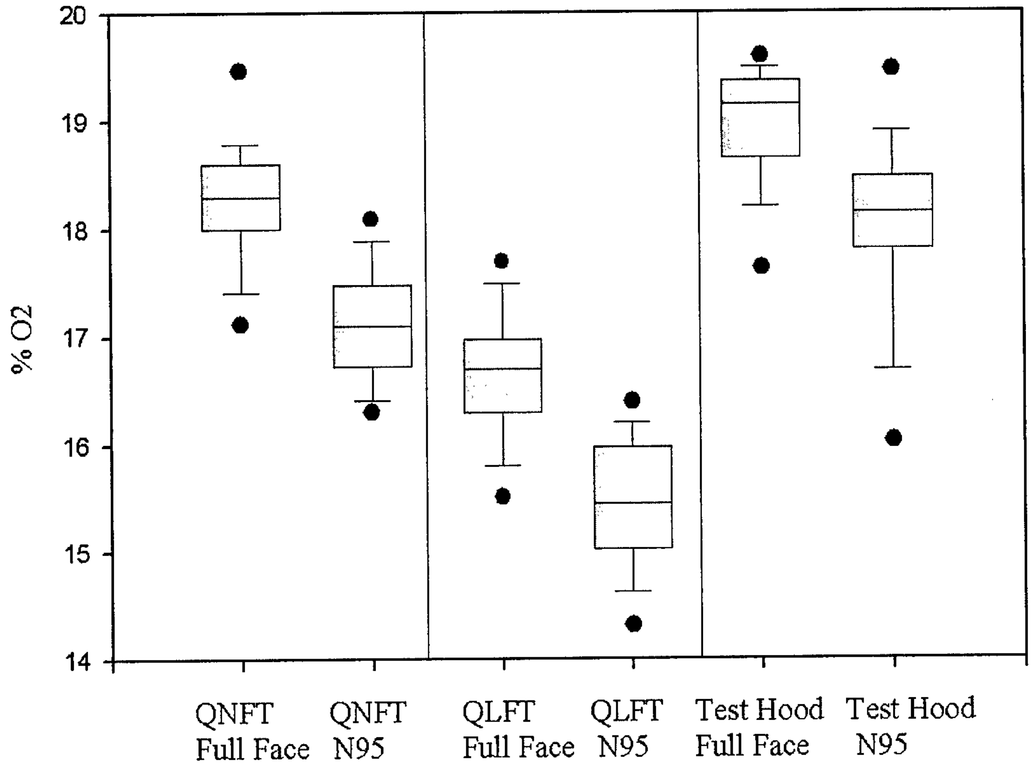

Figure 3.2 Percent O_2 Levels Measured Inside the Respirator or Test Hood. The boxplot shows the following: horizontal lines from bottom, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} percentiles;

- • - shows the range of data

Table 3.3 Mean and Standard Deviation of O_2 Levels Inside the Respirator or Test Hood

		Mean (%)	SD (%)
QNFT (in mask)			
	Full Facepiece	18.3	0.5
	N95 Filtering Facepiece	17.1	0.5
QLFT (in mask)			
	Full Facepiece	16.7	0.6
	N95 Filtering Facepiece	15.5	0.6
Test Hood Level QLFT			
	Full Facepiece	19.0	0.5
	N95 Filtering Facepiece	18.0	0.8

The mean level of O_2 inside the respirator after each of the four fit tests and the level in the test hood was below the level considered O_2 deficient of 19.5% ($p < 0.0001$).

A comparison was made of the O_2 levels present in the two types of respirators. The mean level of O_2 was significantly lower in the N95 filtering facepiece than the full facepiece respirator in the QNFT, QLFT, and inside the test hood ($p<0.0001$).

A regression analysis was conducted for CO_2 and O_2 levels on the height, weight, and BMI of subjects. The largest coefficient of determination, r^2 was 0.17. This indicates less than 17% of the total variation in the data points can be explained by the regression equation. Consequently, the linear relationship with height, weight, and BMI to gas levels in our study population was weakly related .

CO_2 and O_2 Levels for Room Air and Air Next to the Subject

The pre-test mean room CO_2 was 0.0% (below the limit of detection of the meter). The pre-test mean room O_2 was 20.7% (median) with a SD of 0.13%. The mean CO_2 level one-inch in front of the subject's mouth was 0.1% (median) with a SD of 0.10%. The mean O_2 level one inch in front of the subject's mouth was 20.5% (median) with a SD of 0.18%. The mean levels of CO_2 and O_2 measured in the room air (without a test hood) were significantly the same as room air ($p<0.0004$). The air inside of the respirator is significantly different from the air one inch in front of the subject's face without a respirator. Also the air inside of the test hood is significantly different from the air one inch in front of the subject's face without a respirator ($p<0.0001$).

Test Hood Temperature

Temperature characteristics were as follows (mean ± standard deviation [SD] (range)): pre-test room temperature, 66.4°F ± 1.4°F (64.4-68.9°F); inside the test hood after the full facepiece respirator QLFT, 71.8°F ± 2.7°F (67.5-77.4°F); inside the test hood after the N95 respirator QLFT, 74.0°F ± 2.8°F (69.3-80.6°F). The mean increase of temperature inside the test hood was 5.3°F for the full facepiece respirator and 7.5°F for the N95 filtering facepiece respirator (table 3.4). The median values were very close to the mean temperatures. The mean temperature increase inside the test hood after the QLFT with the N95 was higher than with the full facepiece respirator ($p<0.0007$).

Table 3.4 Temperature Increase Mean and Standard Deviation Levels Inside the Test Hood

	Mean (°F)	SD (°F)
QLFT Full Facepiece	5.3	1.6
QLFT N95 Filtering Facepiece	7.5	2.1

Borg Ratio Scale, Heart Rate Data, and O_2 Saturation

The overall mean change in Borg Ratio Scale, heart rate, and arterial O_2 saturation was less than 1% throughout testing.

4.0 DISCUSSION

We found significantly elevated levels of CO_2 and low levels of O_2 inside two types of respirators when subjects wore a test hood to perform QLFTs. A Scott O-Vista full facepiece respirator without a nose cup and an MSA Affinity Pro N95 filtering facepiece respirator without an exhalation valve were selected for testing. A non-human study conducted by NIOSH with a breathing machine indicated that N95 filtering facepiece respirators had higher values of CO_2 and lower values of O_2 inside the mask when compared to full facepiece respirators.[(24)] NIOSH also reported that "the N95 particulate filtering facepieces tested had the highest mean inhaled CO_2 of 3.6% and the lowest mean inhaled O_2 of 16.8%.[(24)] The NIOSH study concluded that higher levels of CO_2 and lower levels of O_2 were present inside the respirator in conjunction with lower ventilation rates.[(24)] We report here very similar findings with human subjects. In addition, the magnitude of these changes is even greater inside the test hood worn during a QLFT.

Wearing respiratory protection inside a test hood significantly elevated the levels of CO_2 the subjects inhaled. For example, the levels of CO_2 in the full facepiece respirator significantly exceeded the STEL during QLFT ($p<0.003$), such as would occur with Bitrex™ or Sweetener. The in-facepiece CO_2 concentration measured approximately 13 minutes after donning was used for comparison with the STEL. Results while wearing a filtering facepiece were even more dramatic. The mean level of CO_2 inside the N95 filtering facepiece respirator while wearing a test hood as part of the QLFT was 4.2%. CO_2 levels inside the facepieces were lower when the test hood was not worn. The mean level of CO_2 in the test hood was 1.4 and 2.2% for the full facepiece and N95 filtering facepiece respectively. Thus the combination of the test hood and the respirator increased CO_2 levels.

The literature reports cardiac events occur at exposure levels of 6% CO_2 for 6 to 8 minutes.[11] Signs of intoxication were produced by a 30 minute exposure at 5%.[5] CO_2 is weakly narcotic at 3%, giving rise to reduced acuity of hearing and increasing blood pressure and pulse.[5] Takahashi *et.al.* reported that increased levels of inhaled CO_2 significantly affected ventilation rate, end-tidal O_2 and CO_2 concentrations, and breathing pressures.[25] The increase in end-tidal CO_2 concentration was caused by the increase in inhaled CO_2, and the increases in end-tidal O_2 concentration and pressure level were induced by the increased ventilation rate which was accelerated by the increase in CO_2.[25] Breathing resistance tended to decrease breathing frequency and volume, and to increase pressure.[25] The resistance decreased end-tidal O_2 concentrations and increased end-tidal CO_2 significantly.[25] Kaye *et.al.* demonstrated that acute exposure to CO_2, traditionally used in psychiatry to stimulate anxiety, can produce mood disorders and the increased frequency of cardiovascular complications associated with chronic stress.[10] The principal psychological changes seen by Kaye *et.al.* were a dose-dependent increase in subjective feelings of anxiety, breathlessness, and a few specific somatic symptoms of fear (i.e., difficulty concentrating, dizziness/lightheadedness, blurred or narrowed vision and feeling hot or flushed).[10] An anxious individual's condition may be aggravated by respirator wear alone. The anxiety may be exacerbated by the higher levels of CO_2 inside the test hood. To our knowledge, no published studies have evaluated health symptoms from elevated CO_2 exposure inside the test hood during QLFT. Measured values of CO_2 during this study reached a maximum of 4.8%. This level may be sufficient to induce health symptoms among susceptible individuals when conducting QFLTs.

Our results are not inconsistent with the hypothesis that inhaled O_2 levels in either style respirator are considered to be O_2 deficient (<19.5%). Even more significant changes are observed when wearing a test hood. The mean O_2 level of the N95 filtering facepiece respirator was 17.1% but decreased to 15.5% when worn inside the test hood. At lowered O_2 levels potential adverse health effects include increased heart rate, some decrease in coordination, increased breathing volume, and impaired thought processes.(13)

There is little information regarding the safe use of a respirator during pregnancy and no guidance regarding safety while being placed inside the test hood during QLFT. In the absence of a respirator, CO_2 production is significantly higher in pregnant women than it is in nonpregnant woman at rest.(20) Given the elevated levels of CO_2 inside the test hood (and low levels of O_2), persons who conduct QLFTs may need to be aware of potential for signs of dyspnea and/or signs of hypoxia. Testing personnel may need to be adequately trained on monitoring for these signs. Alternatively, QNFT may be the preferred method to fit test pregnant women to avoid potential health risks.

Although a mean temperature increase of 7°F was observed during the QLFT with the test hood, our subjects did not complain of high temperatures. This may have been due to the relatively cool temperature of our testing room. This also may have been to the short duration the subject spent inside the test hood. The temperature increase inside the test hood might have been greater if the mean room temperature was higher. This temperature rise may have more of an impact on the heat stress of an individual if starting from a higher ambient temperature.

A worker may not necessarily sense a difference in breathing exertion while wearing a respirator. In this study there was less than a 1% change in mean Borg Ratio Scale values. This is in agreement with other studies where, subjective rating of perceived exertion (RPE) scores remained unchanged with the increased breathing load imposed by the different breathing resistances, indicating that subjects perceived that he/she exerted the same level of effort for all test conditions.[14, 16, 17] Even with the increased burden of breathing higher CO_2 and lowered O_2 inside the test hood, the subject may not be able to perceive the actual increase in breathing exertion brought on by the test hood. Testing monitors may not be able to depend on feedback from the subject on the extent of their increased breathing difficulty.

Significantly higher levels of CO_2 were found in the N95 filtering facepiece when compared to the full facepiece respirator in this study. While the N95 filtering facepiece used in this study has a smaller dead space than the full facepiece respirator, it also has a smaller surface area, less filtering material, and no exhalation or inhalation valves. Thus the N95 filtering facepiece has a higher breathing resistance compared to the full facepiece respirator. CO_2 concentrations present in the test hood during QLFT were higher for the N95 filtering facepiece than the full facepiece ($p<0.0001$). This is consistent with results found in the literature.[9, 14, 15, 24] Johnson *et.al.* concluded that the physiological effects of resistance on breathing are much more pronounced than those due to dead space volume.[9] The NIOSH study also affirmed that the CO_2 level was higher in the N95 filtering facepiece respirator when compared to the full facepiece, as a result this may have implications for the development of NIOSH certification standards for CO_2 concentrations in air purifying respirators.[24]

Results of this study differ from the NIOSH study[24] in that we found no correlation between height, weight, BMI, and levels of CO_2 and O_2. There are many factors that may have influenced this result. The mean age of our study population is lower than the mean age of most working populations. Older populations have a higher BMI, so our results may underestimate the mean values of an older working population. This study did not measure ventilation rates, so they may not have been low enough to show the results found by the NIOSH study. Other factors that may have influenced the results are the respiratory quotient, small sample size, type of body composition (lean or obese), range of subject size, and the amount of carbohydrates ingested.

The mean heart rate and O_2 Saturation changed less than 1% during testing. This is in agreement with the literature.[16, 26] The percentage of arterial O_2 saturation is not a very sensitive test when monitoring partial pressure of O_2 in the blood system. A more precise measurement would have been to invasively measure the blood gas levels.

The subject who received a failing fit factor for the full facepiece QNFT may not have had the straps of the respirator tightened adequately. This may have caused the respirator to slip during the bending exercise.

This study included high efficiency filters with the full facepiece respirator. If lower resistance N95 filters had been used, even larger differences in CO_2 and O_2 levels may have been demonstrated between the full facepiece respirator and the N95 filtering facepiece.

Another observation that came to light during testing was the fact that subjects could not move their head fully in the OSHA specified test hood while wearing the full facepiece respirator used in this study. The full range of motion necessary to carry out fit test exercises could not be achieved. We do not know but suspect this could be a limitation with other make and/or model of full facepiece respirators.

CONCLUSION

When wearing a test hood to conduct QLFT, significantly elevated levels of CO_2 occur. Likewise, O_2 levels dropped significantly. The rise in CO_2 and/or the fall in O_2, may be responsible for many of the subjective complaints that have been heard during this type of testing. Professionals conducting respirator fit tests should be aware of the physiological burdens brought on by these tests. There may be special groups especially sensitive to the QLFT such as the elderly, pregnant women, persons with pulmonary and/or cardiac disease, or persons with psychological disorders such as anxiety, panic disorders, etc.

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APPENDIX 1.0

TERMS SECTION[(27)1]

Acidosis – An increase in the acidity of blood due to an accumulation of acids or an excessive loss of bicarbonate. The hydrogen ion concentration of the fluid is increased thus lowering the pH.

Alveolar ventilation – The movement of air into and out of the alveoli. It is a function of the size of the tidal volume, the rate of ventilation, and the amount of deadspace present in the respiratory system. It is determined by subtracting the deadspace volume from the tidal volume and multiplying the result by the respiratory rate.

Alveolar gradient – The difference between the calculated O_2 pressure available in the alveolus and the arterial O_2 tension.

Alveolar pressure – Air pressure in the alveoli and bronchial tree. It fluctuates below and above atmospheric pressure during breathing; this causes air to enter or leave the lungs.

Anaerobic – able to live without O_2

Anaerobic exercise – Exercise during which the energy needed is provided without use of inspired O_2. This type of exercise is limited to short bursts of vigorous activity.

[1]Definitions from: Taber's Cyclopedic Medical Dictionary unless noted otherwise.

Anxiety – A vague uneasy feeling of discomfort or dread accompanied by an autonomic response; the source is often nonspecific or unknown to the individual; a feeling of apprehension caused by anticipation of danger. It is an altering signal that warns of impending danger and enables the individual to take measures to deal with threat.

Apnea – Temporary cessation of breathing and, therefore, of the body's intake of O_2 and release of CO_2.

Arterial blood gas – Literally, any of the gases present in blood; operationally and clinically, they include the determination of levels of pH, O_2, and CO_2 in the blood.

Body Mass Index (BMI) - The CDC has defined BMI as a way to compare sizes of one person to another person or to an index. BMI is a tool for indicating weight status in adults. It is a measure of weight for height. For adults over 20 years old, BMI falls into one of these categories:

BMI	Weight Status
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

Body Mass Index can be calculated using the person's weight in pounds and their height in inches and the following formula:

BMI = (Weight in Pounds/(Height x Height)) x 703

For example, a person who weighs 220 pounds and is 6 feet 3 inches tall has the following:

BMI = (220/(75 x 75)) x 703 = 27.5. This person would be in the overweight category.

BMI *correlates* with body fat. The relation between fatness and BMI differs with age and gender. For example, women are more likely to have a higher percent of body fat than men for the same BMI. On mean, older people may have more body fat than younger adults with the same BMI. The BMI is not a measure of body fat. Two people can have the same BMI, but a different percent body fat.

Borg Scale - One way to measure how much effort a worker is exerting when performing a task without direct measurement is psychophysics. Psychophysical methods are a consistent, reproducible, quick, inexpensive, and a convenient way to assess the degree of physical strain on the human body. Psychophysical criteria have also been correlated with physiological criteria and some injury indices. Psychophysical methods utilize the results of the central nervous system integration of various information, including the many signals elicited from the peripheral working muscles and joints, and from the central cardiovascular and respiratory functions. All of these signals, perceptions, and experiences are combined and utilized by means of psychophysical methods. To meet the twofold demands of ratio scaling and level estimations, Borg developed the category ratio (CR) scale so that perceptual ratings would increase as a positively accelerating function. The verbal expressions are set so that perceptual intensity increases according to a power function. The number "10" is defined as the strongest effort and exertion a person has ever experienced. Since a person may imagine an intensity that is even stronger, the "absolute" maximum is somewhat higher. By anchoring the highest number at a well-defined perception, with some degree of "sameness" for different individuals, a good point of reference is obtained. Thus, two individuals working at their respective maximal working capacities will be experiencing the same degree of perceived exertion, even though their physical outputs may be different.[2]

Diffusion – The tendency of molecules of a substance (gaseous, liquid, or solid) to move from a region of high concentration to one of lower concentration.

Dyspnea - Air hunger resulting in labored or difficult breathing, sometimes accompanied by pain. It is normal when vigorous work or athletic activity is performed.

Hypercapnia – An increased amount of CO_2 in the blood. Elevated levels of CO_2 in the blood result from inadequate ventilation or from massive mismatches between ventilation and perfusion of the blood. When the CO_2 levels are greater than 45 mm Hg, cerebral vasodilation can occur. Some of the common symptoms of hypercapnia include dizziness, drowsiness, confusion, tremors, and twitching.

Hypoventilation – Reduced rate and depth of breathing that causes an increase in CO2.

Hypoxia – An O_2 deficiency in body tissue or a decreased concentration of O_2 in the inspired air.

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Hypoxemia – Decreased O_2 tension (concentration) in arterial blood, measured by arterial O_2 partial pressure (PaO_2) values. It is sometimes associated with decreased O_2 content.

Lactic acidosis– An accumulation of lactic acid in the blood, often as a result of the inadequate perfusion and oxygenation of vital organs, drug overdoses, skeletal muscle overuse, or other serious illness. Lactic acid is produced more quickly than normal when there is inadequate oxygenation of skeletal muscle and other tissues.

Lactic acid – a product of incomplete glucose metabolism

Metabolism – All energy and material transformations that occur within living cells; the sum of all physical and chemical changes that take place within an organism.

Minute ventilation – The volume of air inhaled and exhaled in 60 seconds, in quiet breathing, usually measured as expired ventilation.

Mood disorder – Any mental disorder that has a disturbance of mood as the predominant feature.

Narcotic – A drug that depresses the central nervous system, thus relieving pain and producing sleep.

Oxygenation – Saturation or combination with O_2, as the aeration of the blood in the lungs.

Oxyhemoglobin dissociation curve – The mathematical relationship between the partial pressure of O_2 and the percentage of saturation of hemoglobin with O_2. There can be a large change in the O_2 tension (mmHg) with only a small change in arterial O_2 saturation (%).

Perfusion – The circulation of blood through tissues.

Portacount Plus Companion – In order to fit test an N95 respirator, the Companion and the Portacount Plus must be used together. If a higher fit factor is required, the Portacount Plus without the N95-Companion must be used. Class 99 and class 100 respirators should be fit tested with the Portacount alone. A maximum fit factor of 200 can be displayed when the Companion is used.

Tidal volume – The volume of air inspired and expired in a normal breath.

Respiratory Acidosis - is caused by inadequate ventilation and the subsequent retention of CO_2

Respiratory exchange ratio (respiratory quotient) - the ratio of CO_2 output to O_2 uptake. Under normal resting conditions, only about 82 percent as much CO_2 is expired from the lungs as there is O_2 uptake by the lungs. That is,

$$R = \text{Rate of } CO_2 \text{ output} / \text{Rate of } O_2 \text{ uptake}$$

The value of R changes under different metabolic conditions. When a person is using exclusively carbohydrates for body metabolism, R rises to 1.00. Conversely, when the person is using exclusively fats for metabolic energy, the R level falls to as low as 0.7.

Stress – Any physical, physiological, or psychological force that disturbs equilibrium. In psychology, stresses include perceptions, emotions, anxieties, and interpersonal, social, or economic events that are considered threatening to one's physical health, personal safety, or well-being.

Vasodilator – causing relaxation of blood vessels

Ventilation – the movement of air into and out of the lungs

Vertigo – The sensation of moving around in space or of having objects move about the person. Vertigo is sometimes inaccurately used as a synonym for dizziness, lightheadedness, or dizziness.

APPENDIX 2.0

POWER CALCULATION

Several recent studies that tested respirator characteristics used a sample size of twenty subjects. We expected the measured CO_2 levels to be between background of about 350 ppm and a maximum of 3.6%. The statistical parameter alpha was set to 5% and beta was set to 80%. To keep the width of the 95% confidence interval (CI) for the mean CO_2 within 0.5% (or the length of the CI approximately 1%), we will need a maximum of 20 test subjects. After completing the testing, the sample size of 20 subjects was sufficient to detect any changes in the mean CO_2 levels, which are ±0.22% on each side of the hypothesized value of 0.5% (OSHA PEL). This sample size was obtained with type I error (alpha) = 0.05 and type II error (beta) = 0.20 (or Power = 80%).

APPENDIX 3.0

DATA ANALYSIS

All sets of data collected for CO_2 and O_2 in the respirator and inside the test hood for each fit test were checked for a normal or lognormal distribution. A Microsoft Excel program was used to evaluate the distribution. The program graphed logprobability plots, a Ratio Metric calculation, a W-test, or a test developed by Filliben.[28] The Shapiro and Wilk Test (W-test) is a method for determining whether sample data have been drawn from a normal distribution, or – if applied to the log transformed sample data – a lognormal distribution.[28] If data form a straight line when plotted on lognormal or normal probability paper that is evidence he/she come from a single population that is log normally or normally distributed.[28] After analyzing the results, it was determined that the data sets listed in table A.3.0 are distributed normally. An example of the program output is displayed by figure A.3.0.

Table A.3.0 Gas level data sets with a normal distribution

CO_2	O_2
QNFT Full Facepiece	QNFT Full Facepiece
QLFT Full Facepiece	QLFT Full Facepiece
QNFT N95 Filtering Facepiece	QNFT N95 Filtering Facepiece
QLFT N95 Filtering Facepiece	QLFT N95 Filtering Facepiece
Test Hood Level during QLFT Full Facepiece	Test Hood Level during QLFT Full Facepiece
Test Hood Level during N95 Filtering Facepiece	Test Hood Level QLFT N95 Filtering Facepiece

Data Description: Quantitative Fit-Test with CO2 Gas Values Measured inside the Full Face Respirator

STEL
3.0

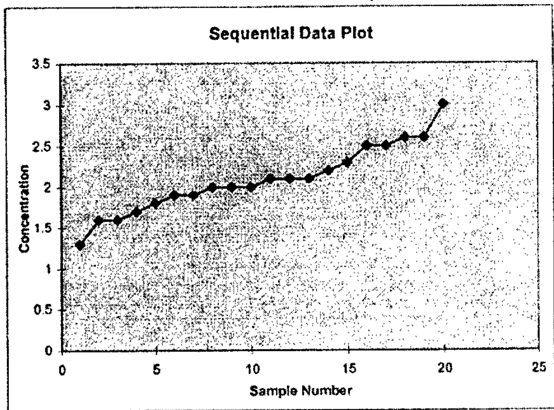
Sample Data (max n = 50) No less-than or greater-than
1.3
1.6
1.6
1.7
1.8
1.9
1.9
2.0
2.0
2.0
2.1
2.1
2.1
2.2
2.3
2.5
2.5
2.6
2.6
3.0

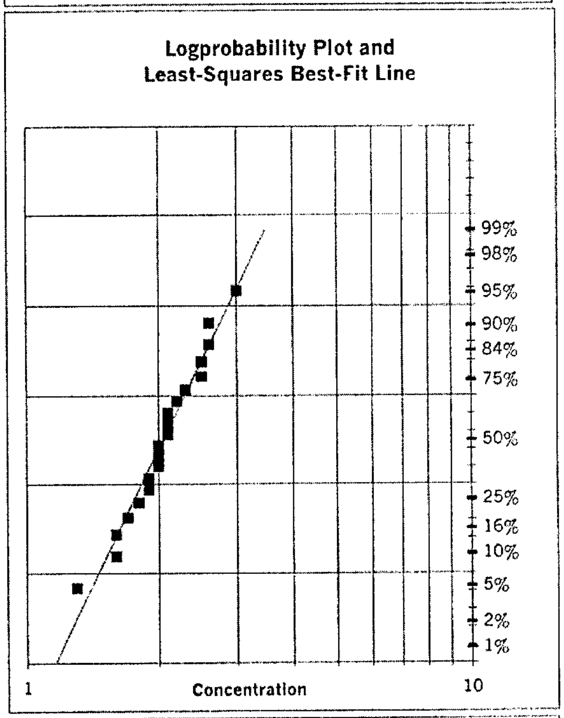
DESCRIPTIVE STATISTICS	
Number of samples (n)	20
Maximum (max)	3
Minimum (min)	1.3
Range	1.7
Percent above OEL (%>OEL)	0.000
Mean	2.090
Median	2.050
Standard deviation (s)	0.409
Mean of logtransformed data (LN)	0.719
Std. deviation of logtransformed data (LN)	0.199
Geometric mean (GM)	2.052
Geometric standard deviation (GSD)	1.220

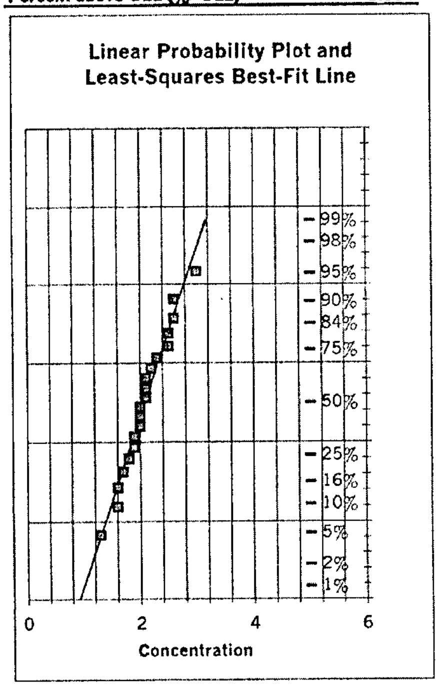
TEST FOR DISTRIBUTION FIT	
W-test of logtransformed data (LN)	0.980
Lognormal (a = 0.05)?	Yes
W-test of data	0.979
Normal (a = 0.05)?	Yes

LOGNORMAL PARAMETRIC STATISTICS	
Estimated Arithmetic Mean - MVUE	2.091
$LCL_{1,95\%}$ - Land's "Exact"	1.942
$UCL_{1,95\%}$ - Land's "Exact"	2.267
95th Percentile	2.846
$UTL_{95\%,95\%}$	3.305
Percent above OEL (%>OEL)	2.811
$LCL_{1,95\%}$ %>OEL	0.586
$UCL_{1,95\%}$ %>OEL	10.247

NORMAL PARAMETRIC STATISTICS	
Mean	2.090
$LCL_{1,95\%}$ - t statistics	1.932
$UCL_{1,95\%}$ - t statistics	2.248
95th Percentile - Z	2.763
$UTL_{95\%,95\%}$	3.07
Percent above OEL (%>OEL)	1.304







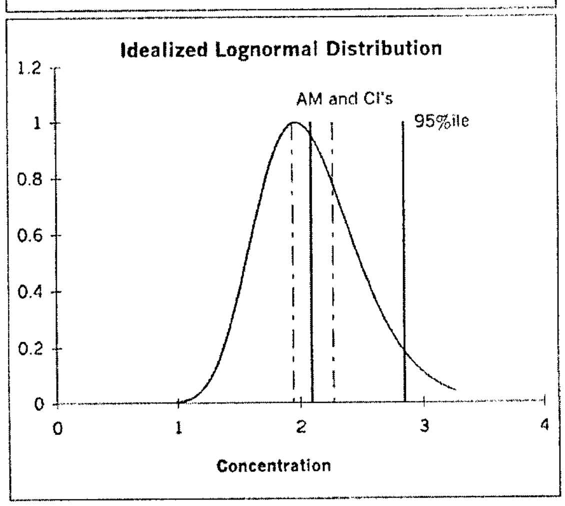


Figure A.3.0. Normal or lognormal testing for QNFT of Full Facepiece Respirator

Testing was conducted to determine if the proposed original hypotheses were true. This study had two null hypotheses that are listed below:

Hypothesis 1: The mean oxygen content of the population of subjects will not drop below the value considered "Oxygen deficient" during the test (19.5% at sea level) in the enclosure or inside of the respirator.

Hypothesis 2: The mean carbon dioxide level of the population of subjects will not rise above the suggested exposure limits during the test in the enclosure.

An example of the analysis that was carried out in GraphPad Quickcalcs is listed below:

Hypothesis Testing

Is the average O_2 in the full facepiece respirator equal to 19.5% for a QNFT?

H_a = full face average O_2 = 19.5%

H_o = full face average O_2 does not = 19.5%

Perform a one sample t test for normal distribution

Full Face Resp O_2/ QNFT	O_2 Deficient
17.1	19.5
17.4	19.5
17.5	19.5
17.7	19.5
18.0	19.5
18.0	19.5
18.1	19.5

18.2	19.5
18.2	19.5
18.3	19.5
18.3	19.5
18.4	19.5
18.4	19.5
18.5	19.5
18.6	19.5
18.6	19.5
18.6	19.5
18.7	19.5
18.8	19.5
19.5	19.5

Full Face O_2	
Avg FF =	18.25
STD FF =	0.543
# samples =	20

Standard	
Avg =	19.50
STD =	0.000
# samples =	20

t-Test: One-Sample Assuming Equal Variances

	Standard		*FF O_2*	
Mean	19.5		18.245	
Difference between two values				1.255
Standard error of difference				0.121
95% confidence interval of				
this difference	1.509	To	1.001	
df	19			
t Stat	10.329			

P(T<=t) two-tail		<0.0001

Therefore reject H_o and the average O_2 level of the FF is less than 19.5%

This analysis was performed for each set of results, such as CO_2 and O_2 level in each type of mask and each type of fit test. Results are listed in table A.3.1.

Table A.3.1 Hypothesis Testing of Gas levels

Sample Location	Test		
	Mean O_2 Levels	Below 19.5%?	P Value
Full Facepiece	QNFT	Yes	<0.0001
	QLFT	Yes	<0.0001
N95 Filtering Facepiece	QNFT	Yes	<0.0001
	QLFT	Yes	<0.0001
Test Hood	QLFT Full Facepiece	Yes	<0.0002
	QLFT N95	Yes	<0.0001
	Mean CO_2 Levels	STEL (3.0%)	P Value
Full Facepiece	QNFT	CO_2 < STEL	<0.0001
	QLFT	CO_2 > STEL	<0.01
N95 Filtering Facepiece	QNFT	CO_2 < STEL	<0.0001
	QLFT	CO_2 > STEL	<0.0001
Test Hood	QLFT Full Facepiece	CO_2 < STEL	<0.0001
	QLFT N95	CO_2 < STEL	<0.0001

An interesting aspect of the respirators was the question, "which has more of an effect on the gas levels, the amount of dead space or breathing resistance?" The Scott O'Vista full facepiece has a larger dead space but the N95 filtering facepiece has a higher breathing resistance. A comparison was made between the gas levels of the two types of masks. An example is listed below:

Hypothesis Testing

Is the average CO_2 level in the full facepiece respirator less than the N95?

H_a = alternative hypothesis = full face average CO_2 < N95 averageCO_2

H_o = null hypothesis = full face average CO_2 > or = to N95 average CO_2

Perform a t test for normal distribution with population variance unknown

Full Face Resp CO_2/ QNFT(%)	N95 Resp CO_2/ QNFT(%)
1.3	1.6
1.6	2.1
1.6	2.2
1.7	2.2
1.8	2.6
1.9	2.7
1.9	2.7
2.0	2.8
2.0	2.8
2.0	3.0

2.1	3.0
2.1	3.0
2.1	3.0
2.2	3.1
2.3	3.1
2.5	3.2
2.5	3.2
2.6	3.3
2.6	3.4
3.0	3.8

Full Face CO_2 (%)	
Mean FF =	2.09
SD FF =	0.409
# samples =	20

N95 CO_2 (%)	
Mean N95 =	2.84
SD N95 =	0.510
# samples =	20

t-Test: Two-Sample Assuming Equal Variances

	Full Face Resp CO_2	*N95 CO_2*
Mean	2.09	2.84
Variance	0.167	0.260
Observations	20	20
Pooled Variance	0.214	
df	38	
t Stat	5.129	
P(T<=t) one-tail	4.437E-06	
t Critical one-tail	1.686	
P(T<=t) two-tail	8.873E-06	
t Critical two-tail	2.024	

Let alpha = 0.05; the critical value of t = 1.686

Reject H_o unless t computed < 1.686

t computed = 5.129 which is > 1.686

Therefore reject H_o and the average CO_2 level of the FF is less than the N95 CO_2 level

p value =4.437E-06

Through this analysis of data, table A.3.2 was constructed of gas levels of the two types of masks along with levels in the test hood.

Table A.3.2 Comparison of Respirator Style (Full Facepiece versus Filtering Facepiece) with Measured Mean CO_2 and O_2 Levels Obtained During QNFT and QLFT

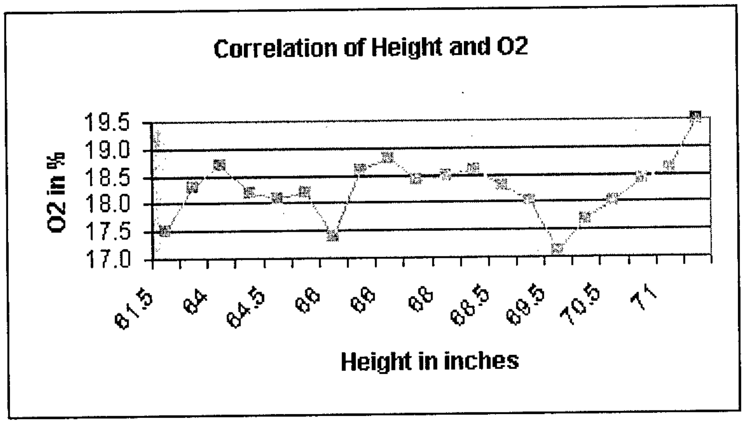
Sample Location	CO_2	p value
QNFT	N95 Filtering Facepiece > Full Facepiece	<0.0001
QLFT	N95 Filtering Facepiece > Full Facepiece	<0.0001
Test Hood Level QLFT	N95 Filtering Facepiece > Full Facepiece	<0.0001
	O_2	p value
QNFT	N95 Filtering Facepiece < Full Facepiece	<0.0001
QLFT	N95 Filtering Facepiece < Full Facepiece	<0.0001
Test Hood Level QLFT	N95 Filtering Facepiece < Full Facepiece	<0.0001

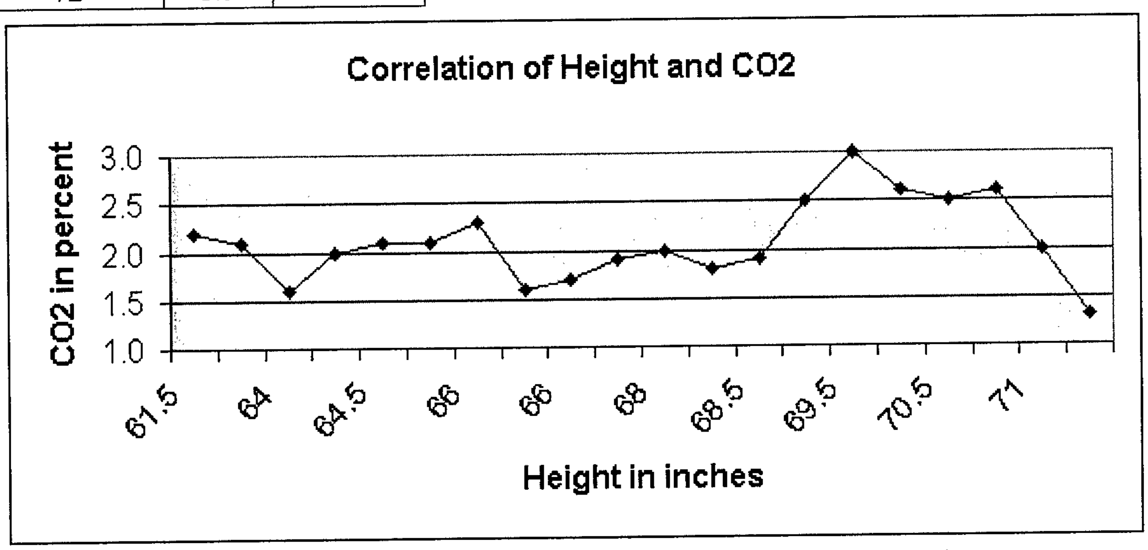
The NIOSH study showed that the lower the breathing rate, the more extreme the measured gas levels were found. We compared CO_2 and O_2 levels to height, weight, and BMI of the subjects. First the data was graphed with a correlation coefficient and ANOVA with regression was calculated. An example is presented below:

QNFT Full Facepiece CO_2/O_2

Height (inches)	Resp CO_2 % QNFT	Resp O_2 % QNFT
61.5	2.2	17.5
63	2.1	18.3
64	1.6	18.7
64.5	2.0	18.2
64.5	2.1	18.1
65	2.1	18.2
66	2.3	17.4
66	1.6	18.6
66	1.7	18.8
67.0	1.9	18.4
68	2.0	18.5
68.5	1.8	18.6
68.5	1.9	18.3
68.5	2.5	18.0
69.5	3.0	17.1
70	2.6	17.7
70.5	2.5	18.0
71	2.6	18.4
71	2.0	18.6
72	1.3	19.5

Correlation of Height and CO_2 = 0.194
Correlation of Height and O_2 = 0.212





SUMMARY OUTPUT QNFT Full Facepiece Height versus CO_2

Regression Statistics	
Multiple R	0.1939
R Square	0.0376
Adjusted R Square	-0.0159
Standard Error	2.9769
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.2311	6.2311	0.7031	0.4127
Residual	18	159.5189	8.8622		
Total	19	165.75			

	Coeff.	*STD Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	64.3235	3.5530	18.1039	0.0000	56.8588	71.7881	56.8588	71.7881
X Variable 1	1.4003	1.6699	0.8385	0.4127	-2.1081	4.9086	-2.1081	4.9086

y = 64.3235+ 1.4003x

A summary of the results are presented in Table A.3.4.

Table A.3.4 Height, Weight, and BMI and CO_2 and O_2 versus

QNFT Full Facepiece	**Correlation Coefficient**	**Regression**		**ANOVA**	
height/CO_2	0.194	R^2 =	0.0376	F =	0.417
height/O_2	0.212		0.045		0.368
weight/CO_2	0.199		0.04		0.4
weight/O_2	0.129		0.017		0.587
BMI/CO_2	0.153		0.023		0.52
BMI/O_2	0.026		0.026		0.915
QLFT Full Facepiece					
height/CO_2	0.282		0.08		0.228
height/O_2	-0.164		0.027		0.49
weight/CO_2	0.411		0.169		0.072
weight/O_2	-0.13		0.017		0.586
BMI/CO_2	0.327		0.11		0.159
BMI/O_2	-0.0069		0.005		0.77

QNFT N95 Filtering Facepiece	Correlation Coefficient	Regression		ANOVA	
height/CO_2	0.049	R^2 =	0.002	F =	0.838
height/O_2	0.127		0.016		0.595
weight/CO_2	0.192		0.037		0.417
weight/O_2	0.149		0.022		0.531
BMI/CO_2	0.171		0.029		0.471
BMI/O_2	0.135		0.018		0.57
QLFT N95 Filtering Facepiece					
height/CO_2	0.185		0.034		0.435
height/O_2	0.116		0.013		0.627
weight/CO_2	-0.003		0.0001		0.989
weight/O_2	0.25		0.062		0.289
BMI/CO_2	-0.119		0.014		0.618
BMI/O_2	0.238		0.057		0.312

The same type of t test hypothesis testing was also conducted for test hood temperature increase, difference before and after fit test for Borg Ratio Scale, arterial O_2 saturation, and heart rate data.

APPENDIX 4.0

FUTURE RESEARCH

We used respirators thought to have a maximum effect on gas levels. Future testing could be conducted on different types of respirators. Selecting a full facepiece respirator with a nose cup and a filtering facepiece respirator with an exhalation valve may produce additional insight on effects of these parameters. This may focus on what impact the smaller dead space and lower breathing resistance has on the gas buildup inside the respirator.

The NIOSH study showed a relationship between breathing rates of their automated machine and the gas levels present in the respirators. Our study did not measure breathing rates so a comparison could not be made on the effect of breathing rates and gas levels. It would be interesting to determine what effect the breathing rate or the person's size has on the gas levels of the respirator.

Initial testing of respirators in the 1960's and 1970's determined that respirators would not have a significant effect on workers. These tests were conducted with only a few subjects and the subjects were at rest. Later tests conducted with a person at 80% V_{O2}max revealed a noteworthy difference on gas levels present. It may be beneficial to establish the gas levels present when a person is breathing at 80% of their V_{O2}max in different respirators.

Since health symptoms of CO_2 include vertigo, intoxication, and narcotic effects, it might be interesting to test subjects for balance when wearing a respirator. The Ergonomics Program has a very sensitive device to conduct this testing in the form of a force plate to evaluate stability.

The future study could test at 80% of the subjects $V_{O2}max$ to measure the biggest difference on the effect of the respirator.

APPENDIX 5.0

LESSONS LEARNED

When I discussed this project with my advisor, he recommended that I borrow a gas analyzer from NIOSH to complete the study. I obtained permission from NIOSH for this purpose. The first discussion of the project involved measuring gas levels in the test hood of the QLFT, these would be low levels of CO_2. Then we decided to measure in mask gas levels. When the time came for pilot testing, I soon found out that the equipment would not work for this application. The CO_2 meter was designed for indoor air quality (IAQ) investigations. During IAQ surveys, investigators are looking for slightly elevated CO_2 levels, so the meter had a maximum range of 5000 ppm (0.5%). Exhaled human breath can contain up to 5% CO_2. When I connected the meter for the first time, it quickly exceeded its range. My next step was to call many businesses in the Cincinnati area that may use this type of equipment and request borrowing the meter. This effort was not successful. I had previously searched on the internet for equipment that could be rented in case it was not available from NIOSH. This proved to be a time saver. The meter used for this study was actually designed for monitoring landfills. As it turns out, landfills can off gas 50% methane and 50% CO_2. A further inquiry turned up that the rental cost would be covered by a pilot project research training grant from the University of Cincinnati through its Education and Research Center.

Dr. McKay volunteered to help me conduct some pilot testing. This was invaluable to practice the test method and data collection. One difficulty I had was connecting the gas analyzer hose. I found that I had to wait for the subject to stop breathing momentarily while I made the connection. If the subject continued to breath when the hose was disconnected, it may have altered the results. I also brought additional volunteers into the lab to practice conducting pilot testing. I went through several revisions of the data collection form. Finally, I arranged the form in a column that I could follow from top to bottom. When I tried a row format, the cell became too narrow to contain the information and the form would have been very long and unmanageable. I also color-coded the cells to correspond to a particular piece of equipment as a memory tickler.

I depended on email to contact most subjects for their scheduled appointments. I did not obtain the subjects phone number before I scheduled testing. There were several incidents where a courtesy reminder call to the subject beforehand would have prevented a "no show".

I provided bottled water for the subjects during testing. This worked out well. After wearing the respirator, the subjects tended to feel warm and found a drink refreshing.

I obtained 17-liter containers of calibration gas. I just about ran out during testing. If this test was repeated, I would recommend getting two containers each of calibration gas. I did use additional gas to practice calibrating the analyzer. It took awhile to become comfortable using the gas analyzer's computer menu screens and manual.