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Respiratory Flow Characteristics of Intensive Care Healthcare Workers Performing Patient Care Activities

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Respiratory Flow Characteristics of Intensive Care Healthcare Workers Performing Patient Care Activities

Shawn R. Williamson

Thesis submitted
To the Benjamin M. Statler
College of Engineering and Mineral Resources
At West Virginia University

In partial fulfillment of the requirements for the degree of

Master of Science in
Industrial Hygiene

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Morgantown, West Virginia
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Abstract

Respiratory Flow Characteristics of Intensive Care Healthcare Workers Performing Patient Care Activities

Shawn R. Williamson

In the United States, under OSHA regulations, all respirators used in the workplace must be certified by the National Institute of Occupational Safety and Health (NIOSH). Under current NIOSH standards, loose-fitting powered air-purifying respirators (PAPR) must provide a minimum operational flow of 170 liters per minute. The objective of this study was to characterize the breathing flow rates of nine health care workers during patient care activities typically performed in a hospital's intensive care unit. This characterization will be used to determine the feasibility of lowering the minimum operational flow rate of PAPRS used in health care settings.

Each participant wore a portable respiratory flow recording device during twelve simulated patient care activities. The patient care activities include: changing bedding, turning and positioning the patient, patient health history review, hooking up a cardiac monitor, inserting and starting an IV, drawing blood tubes, patient passive range of motion exercises, inserting setting up and removing a foley catheter, bathing and turning the patient, performing CPR, and inserting and removing a breathing tube.

Of the nine participants, there were four males and five females. The minute volume (MV, L/min), mean inhalation flow (MIF L/min), and peak inhalation flow (PIF L/min) was calculated for each participant during each patient care activity. The mean MV, MIF, and PIF across all participants and patient care activities were 21, 50, and 86 L/min, respectively. Two-sample t-tests were performed to compare the effect of gender on MV, MIF, and PIF. There was a significant difference in MV, MIF, and PIF for males and females ($\alpha=0.05$). An analysis of variance was conducted to compare the effect of participant and activity on MV, MIF, and PIF. Both participant and patient care activity had a significant effect on the mean MV, MIF, and PIF ($\alpha=0.05$). A post hoc analysis of the effect of participant and activity on MV, MIF, and PIF was performed through a Tukey HSD test. The results of this study illustrate that lowering the required minimum operational flow of PAPRs may be feasible; however, participant does have a significant effect on breathing flow characteristics. Thus, further analysis is needed to incorporate, correlations between age, weight, body surface area, and body mass index

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Nomenclature

Abbreviations

APF	Assigned Protection Factor
ATD	Aerosol Transmissible Diseases
CFR	Code of Federal Regulations
CL	Confidence Level
CPR	Cardiopulmonary resuscitation
HSD	Honestly Significant Difference
LPM	Liters per Minute
MIF	Mean Inhalation Flow
MV	Minute Volume
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PAPR	Powered Air Purifying Respirator
PDL	Pressure Data Logger
PIF	Peak Inhalation Flow
SD	Standard Deviation
STEPS	WVU Center for Simulation Training and Education for Patient Safety
TL	Tolerance limit
LS	Least Square
BMI	Body Mass Index
CI	Confidence Interval

Symbols

α	Statistical Significance Level
$\bar{x}$	Sample Mean
γ	Tolerance Level: Probability that at least P proportion is less than
n	number of observations

1 Introduction

1.1 General Respiratory Protection

In general, a respirator is a protective device that covers the nose and mouth or the entire face or head to protect the user from hazardous atmospheres. There are two main types of respirators, air-purifying respirators and atmosphere-supplying respirators. An atmosphere-supplying respirator provides the user with uncontaminated air from an external source, such as a tank. In contrast, an air-purifying respirator relies on an air filter element or a cartridge to capture specified airborne contaminants before the user inhales them.

Respirators are further classified into tight-fitting or loose-fitting facepiece; a tight-fitting respirator requires a continuous seal between the respirator and the user's face. Tight-fitting respirators are available in two basic types half mask, and full face. In contrast, loose-fitting respirators do not require a continuous seal with the user's face to provide protection. There are both filtering facepiece, also referred to as disposable, and reusable tight-fitting respirators.

In general, reusable tight-fitting respirators are elastomeric type respirators meaning that the facepiece is made of rubber or silicone that forms a seal with the user's face. All elastomeric respirators are equipped with an exhalation valve. Elastomeric respirators have replaceable cartridges and or filters. The type of filter or cartridges depends on the type of airborne contaminants potentially present. Cartridges are generally used to capture nonparticulate hazards, such as gases or vapors. Combination filters and cartridges can be used to provide protection against both particulates and gases or vapors.

The filtering facepiece respirator (FFR) does not require a filter cartridge because the entire respirator is the filter. Filtering facepiece respirators may be equipped with an exhalation valve. The most commonly used FFR is the NIOSH certified N95 without exhalation valve.

1.1.1 Respirator Approvals and Regulations

In accordance with current Occupational Safety and Health regulations, "A respirator shall be provided to each employee when such equipment is necessary to protect the health of such employee." Currently, all respirators used in the workplace must be certified by the National Institute for Occupational Safety and Health (Occupational Safety and Health

Administration, 1998). In 1972, shortly after the enactment of the Occupational Safety and Health Act, the National Institute for Occupational Safety and Health (NIOSH) and the U.S. Bureau of Mines jointly promulgated 30 C.F.R. part 11. This regulation described specific approvable procedures and established test requirements for respirators. Since then, in the United States, all respirator approval and certification functions are now the sole responsibility of NIOSH. The current approval regulations can be found in 42 C.F.R. part 84. All NIOSH certified respirators are accompanied with a subsequent approval label. (Colton, 2012).

1.1.2 Particulate Filter Classifications

NIOSH also assigns class designations to particulate filters used for respiratory protection. For example, the term N95 refers to the filter classification; NIOSH certifies nine classes of filters. The letter in the designation can either be N, R or P, which corresponds to "not resistant to oil", "somewhat resistant to oil" and "strongly resistant to oil (oil proof)", respectively. The number refers to the efficiency rating of the filter. For example, an N95 respirator is at least 95% efficient at removing oil free aerosols of at least 0.3 microns in aerodynamic diameter. All filters with one of these class designations are discarded at the end of their service life; if they are a permanent part of the respirator, the entire respirator is discarded. (NIOSH, 2018)

1.1.3 Assigned Protection Factor

OSHA has established assigned protection factors for different types and classes of respirators. The assigned protection factor is a numerical representation of the respiratory protection level provided by that respirator or class of respirator when worn properly. For example, a half-mask air-purifying respirator that has an assigned protection factor of 10 means that "the respirator will reduce the concentration breathed in by ten times compared to the actual airborne concentration." (Colton, 2012)

Type of respirator ^{1, 2}	Quarter mask	Half mask	Full facepiece	Helmet/hood	Loose-fitting facepiece
1. Air-Purifying Respirator	5	³ 10	50		
2. Powered Air-Purifying Respirator (PAPR)		50	1,000	⁴ 25/1,000	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
• Demand mode		10	50		
• Continuous flow mode		50	1,000	⁴ 25/1,000	25
• Pressure-demand or other positive-pressure mode		50	1,000		
4. Self-Contained Breathing Apparatus (SCBA)					
• Demand mode		10	50	50	
• Pressure-demand or other positive-pressure mode (e.g., open/closed circuit)			10,000	10,000	

Notes:

¹Employers may select respirators assigned for use in higher workplace concentrations of a hazardous substance for use at lower concentrations of that substance, or when required respirator use is independent of concentration.

²The assigned protection factors in Table 1 are only effective when the employer implements a continuing, effective respirator program as required by this section (29 CFR 1910.134), including training, fit testing, maintenance, and use requirements.

³This APF category includes filtering facepieces, and half masks with elastomeric facepieces.

⁴The employer must have evidence provided by the respirator manufacturer that testing of these respirators demonstrates performance at a level of protection of 1,000 or greater to receive an APF of 1,000. This level of performance can best be demonstrated by performing a WPF or SWPF study or equivalent testing. Absent such testing, all other PAPRs and SARs with helmets/hoods are to be treated as loose-fitting facepiece respirators, and receive an APF of 25.

⁵These APFs do not apply to respirators used solely for escape. For escape respirators used in association with specific substances covered by 29 CFR 1910 subpart Z, employers must refer to the appropriate substance-specific standards in that subpart. Escape respirators for other IDLH atmospheres are specified by 29 CFR 1910.134 (d)(2)(ii).

Table 1.1: OSHA Assigned Protection Factors

1.1.4 Respirator Fit-Testing

As previously stated, all tight-fitting respirators must form a continuous seal with the users face in order to function properly. Thus, the Occupational Safety and Health Administration mandates that anyone who is required to wear a tight-fitting respirator be fit tested at least annually. Fit testing may be either quantitative or qualitative. Qualitative fit testing works by subjecting the user to a non-harmful irritant while wearing the respirator then evaluating their reaction, or lack thereof, to determine if there is any leakage. In contrast quantitative fit testing is preformed using a machine that quantitatively measure seal leakage.

1.2 Powered Air Purifying Respirators

A powered air-purifying respirator (PAPR) uses a battery powered blower to move air through a filter and to the user. PAPRs are also categorized into tight-fitting or loose-fitting. However, the primary focus of this research is loose-fitting PAPRs. Figure 1.1 depicts a loose-fitting powered air purifying respirator.

Figure 1.1 (OSHA)

1.3 Powered Air Purifying Respirators in Healthcare

In accordance with current OSHA regulations, "A respirator shall be provided to each employee when such equipment is necessary to protect the health of such employee." (Occupational Safety and Health Administration, 1998). Hospitals and other healthcare environments present a variety of challenging safety and health issues. In the healthcare setting, workers may be exposed to a variety of airborne contaminants such as cleaning chemicals, hazardous drugs, and aerosol transmissible diseases.

Aerosol transmissible diseases (ATD) are diseases transmitted when infectious agents, which are suspended or present in particles or droplets, contact the mucous membranes or are inhaled. (National Institute for Occupational Safety and Health, 2020) Humans can produce respiratory aerosols by several means including, breathing, talking, coughing, and sneezing. It is vitally important to protect healthcare workers from exposure to any ATD that may be present in those aerosols. Filtering facepiece respirators and surgical masks are the most frequently used respiratory protection devices in the health care environment.

PAPRs are utilized in a variety of different situations in healthcare environments. PAPRs provide several distinct advantages over both elastomeric respirators and disposable respirators. Since PAPRs do not seal to the users face they are not required to be fit tested, PAPRs can also be less physiologically straining since they do not rely on the users respiratory system to move air through the filters, for this same reason PAPRs are also generally considered more comfortable. Loose fitting PAPRs provide continuous positive pressure airflow to the user, which in turn, helps the user stay cool and comfortable. (3M United States, 2018) Also, as shown in figure 1.1 PAPRs have a significantly higher assigned protection factor compared to other air purifying respirators.

1.4 Objective

The objective of this study is to characterize the inhalation breathing flows of healthcare workers performing patient care activities typically performed in an intensive care unit. Data collected will be used to determine the feasibility of lowering the minimum operational flow rate

of loose fitting PAPRs used in the healthcare setting. Currently NIOSH regulations require the minimum operational flow of PAPRS to be at least 170 liters per minute. However, this regulation was written based on data collected from industry related work activities. Lowering the minimum operational flow rate for use in healthcare settings would be advantageous for several reasons, including reducing device weight, longer run times, and reducing manufacturing costs.

2 Literary Review

PAPRs are generally considered to provide a high level of respiratory protection because they create a positive pressure environment inside the hood or mask. Airborne contaminants are unlikely to naturally move from a lower pressure environment to a higher-pressure environment. However, if the user's peak inhalation flowrate exceeds the PAPRs air flow delivery rate, a negative pressure environment can be created and airborne contaminants can be drawn into the mask or hood. Thus, it is of vital importance to understand the respiratory flow characteristics of the user before any adjustments to the minimum operational flow are made. However, at current flow requirements it has been found that while high workloads can create occasional negative pressure spikes, they have minimal effect on the protection provided by the respirator. (Janssen, Anderson, Cassidy, Weber, & Nelson, 2005)

Very limited research studies have examined the respiratory flow characteristics of health care workers. One problem attributing to the minimal research on the feasibility of lowering the minimal operational flow of PAPRs used in healthcare settings was the lack of technology to accurately record respiratory flow rates during healthcare related activities proper. The S.E.A group's pressure data logger (PDL) device solves this problem. The performance of the S.E.A pressure data logger was assessed and compared with a respiratory flow recorder. Both devices were assessed by recording the respiratory flows of 15 subjects performing a series of simulated healthcare work activities. The assessment found that the S.E.A groups PDL produced minimal variability and would be the best choice to further investigate the respiratory flow characteristics of health care workers. The recorded respiratory flows during the assessment provide the some preliminary insight into the respiratory flow characteristics of healthcare workers performing healthcare related activities. (Zhu, et al., 2018)

Part one of this study was “a pilot study of minimum operational flow for loose-fitting powered air-purifying respirators used in healthcare cleaning services.” The study examined the breathing flow characteristics of nine health care workers to explore the feasibility of lowering the minimum operational flow rate of PAPRS used in the health care setting. The nine subjects in the study wore a S.E.A PDL while performing cleaning and disinfecting work typically performed in an Isolation unit. The study found that the average MV, MIF and PIF for isolation unit cleaning work was 33, 74, and 107 the respective maximum airflow rates were, 41, 97 and 145. The maximum flow rates are all lower than the required minimum operational flow rate of 170 liters per minute. (Zhu , et al., 2019)

3 Methods

3.1 Participants

Nine health care workers were recruited to participate in the study. Approval from the West Virginia University Institutional Review Board (protocol number 2007061495) was obtained prior to subject recruitment. All subjects were recruited from WVU Medicines Ruby Memorial Hospital. Before participating, all subjects reviewed and signed the "Consent Information and HIPPA Form" and completed an OSHA respirator medical questionnaire. All OSHA medical clearance questionnaires were reviewed and approved before the study began. Of the nine participants, two were respiratory therapists and seven were registered nurses. The participant's age, weight and height were 28.2 ± 6.06 years, 69.89 ± 4.20 inches and 171 ± 40.69 pounds (means $\pm$ standard deviation), respectively. Table 3.1 provides individual data for each participant.

Table 3.1 Participant Physical Measurements

Participant #	Sex	Age	Height	Weight
1	F	23	73	160
2	F	23	66	150
3	F	27	66	131
4	M	29	71	200
5	F	26	67	140
6	M	26	72	198
7	F	24	64	125
8	M	35	75	185
9	M	41	75	250

3.2 Instrumentation

Inhalation and exhalation pressure were measured using the S.E.A Pressure Data Logger (PDL). This device measures and records pressure inside of a Sündstrom SR100 half mask elastomeric respirator using a small silicon adapter attached to the respirator's exhalation port (Figure 3.1). The PDL records the pressure inside the respirator at a sampling rate frequency of 50 Hz. The PDL device is capable of sampling continuously for 8 hours. After the data is collected, the included software converts the data points into respiratory flow using a second order polynomial best fit calibration curve.

Figure 3.1 Sündstrom SR100 Silicon adapter

3.2.1 Pressure Data Logger Calibration

In order to accurately determine respiratory flow, the pressure recorded by the PDL must be converted to flow using four calibration constants derived from an inhalation and exhalation second order polynomial best fit calibration curve. The filter characterization setup was done by fully sealing the Sündstrom SR100 half mask elastomeric respirator to a mannikin head, a TSI Airpro Micromanometer Model AP800 (TSI, 2017), was then attached to the silicon exhalation valve adapter, shown in Figure 3.1. The mannikin's airway was then connected to the laboratory vacuum line. In order to measure flow, a TSI 5000 series flow meter was connected in line with the mannikin's airway.

Once the setup was completed, the vacuum was started. Utilizing the flow meter output, the airflow was increased in 10 liters per minute intervals up to 250 liters per minute. At each 10 liters per minute interval, the pressure displayed on the TSI Airpro Micromanometer was recorded. Since the laboratory vacuum line would only supply approximately 90 liters per minute, a Shop-Vac and a variable transformer device were used to produce flowrates greater than 90 liters per minute. Once all the data points were collected, the airflow was reserved, and

the process was repeated to develop an exhalation calibration curve. The collected pressure and flow data points were input into Microsoft Excel and a graph was produced for both the inhalation and exhalation curves. Using Microsoft Excel, a 2nd order polynomial best fit trend line was fit to the data and its corresponding $ax^2 + bx + c$ equation was displayed for both the inhalation and exhalation data points. The a and b coefficients for the inhalation curve and the exhalation curve of the polynomial equation are inputted as "Aneg", "Bneg" and "Apos" and "Bpos" respectively. (The S.E.A Group, 2015) The graphs for the exhalation and inhalation calibration curves are shown and Figure 3.2 and 3.3 respectively.

Figure 3.2 Inhalation Calibration Curve

Figure 3.3 Exhalation Calibration Curve

3.3 Experimental Design and Procedure

In order to best simulate a hospital environment, this study was conducted in the West Virginia University Patient Safety Simulation Center. All patient care activities were completed on a mannikin (Figure 3.4 & Figure 3.5). All necessary equipment for each patient care activity was provided by the STEPs lab. This included an IV start kit, blood draw tubes, needles, tourniquet suction line, cardiac monitor, laryngoscope, endotracheal tube, bathing items (wash basin, rags, etc.), and a Bard® Foley catheter kit.

Each subject was quantitatively fit tested using a TSI PortaCount (serial number: 8038102806) before they began the study. The fit testing results can be found in the appendix of this report. Each participant wore either a small/medium or medium/large Sündstrom SR100 half mask elastomeric respirator with the PDL device attached. The inspiratory flows of each participant were recorded during three randomized replications of twelve patient care activities typically performed in an intensive care unit. The patient care activities included: changing bedding, turning and positioning the patient, patient health history review, hooking up a cardiac monitor, inserting and starting an IV, drawing blood tubes, patient passive range of motion exercises, inserting setting up and removing a foley catheter, bathing and turning the patient, performing five rounds of CPR (30 compressions 2 breaths equals one round), and inserting and removing a breathing tube.

Figure 3.5: STEPs mannikin

Figure 3.5: STEPs mannikin 2

For the inspiratory flows of each activity to be analyzed separately, the participants were asked to hold their breath for five to ten seconds at the start and end of each activity. The start and stop times for each activity were also manually recorded. This allowed for a graphical indicator of the start and end time of each activity (Figure 3.6). Each participant was asked to follow standard hospital procedures and complete the activity as they normally would. Due to individual variables in speed and technique, the time required to complete the patient care activities varied by participant. It should also be noted that participants 3, 4 and 5 talked intermittently during the patient care activities, while the remaining participants were asked to not talk, unless the activity required communication E.g. patient health history.

Figure 3.6: Flow vs. Time Participant # 2

4 Data Analysis

Once the data was downloaded from the PDL device, the PDL software was then used to download the participants respiratory flows as a comma separated value (CSV) file. The file was then opened in Microsoft Excel and elapsed time values were added to the data. The PDL device records both positive and negative flows, however, due to the low resistance of the exhalation values, it is recommended by the manufacturer that the exhalation flows not be used for analysis.

Thus, only the negative values created by inhalation flow through the air purifying, P100 filter were used for analysis.

The participants respiratory flow rates were graphed in 15-minute intervals. The graphs were then examined, and the recorded activity start and stop time were either confirmed or adjusted to match when the participant held their breath. The data was then filtered and separated by replication and activity, the total volume inhaled, 50th percentile inhalation flow, 75th percentile inhalation flow, minute volume (MV), mean inhalation flow (MIF), and peak inhalation flow (PIF) were calculated for each activity replication. Minute volume was calculated by dividing the total volume inhaled by the elapsed time. Mean inhalation flow was calculated by taking the average of all the inhalation flow for the activity. The peak inhalation flow was calculated by taking the average of the inhalation flows greater than the 75th percentile to equate for the top 25% of inhalation flow values. In order to report with 95% confidence that the 95 % of flows are less than a specific value, upper tolerance limits were calculated for MV, MIF, and PIF. across all participants for each activity. The following formula (Figure 4.1) was used to calculate upper tolerance limits. Where the K factor is a pre-determined, statistical value such that the probability is γ that at least a proportion P of the distribution will be less than $\bar{x} + k$, where $\bar{x}$ and s are estimates of the mean and the standard deviation. (National Bureau of Standards , 1963)

$$TL_{95,95} = \bar{x} + K_{\gamma,P,n} * s$$

Figure 4.1: Tolerance Limit Equation

4.1 Statistical Analysis

All statistical analysis was performed using JMP Pro 15. Each participant's, MV, MIF, and PIF for each activity replication were used for the analysis. An analysis of variance was conducted to compare the effect of participant and activity on MV, MIF, and PIF. The confidence intervals for each activity and participant are also reported. If a significant difference was determined through the analysis of variance results, then a post hoc analysis of the effect of participant and activity on MV, MIF, and PIF was performed through the Tukey's honestly significant difference test. The average MV, MIF, and PIF for all participants both male and

females was calculated, and three two sample t-tests were performed to determine if gender had a significant effect.

5 Results and Discussion

The results of this study are summarized in the following tables. Activities 1 through 12 are defined as; insert setup and remove a foley catheter, changing bedding, inserting and removing a breathing tube, patient health history review, hooking up a cardiac monitor, drawing blood tubes, passive range of motion exercises, turning and positioning the patient, suctioning the patient, performing CPR, inserting and starting an IV, and bathing and turning the patient, respectively (Table 5.1). Each participant's MV, MIF and PIF and upper tolerance limits across all activities are shown in Table 5.2. The upper tolerance limits indicate with 95% confidence, that 95% of the data is below the indicated value. Also, the confidence intervals for each participant are reported in Table 5.3.

Table 5.1: Patient Care Activities Summary

Activity 1	Insert Setup and Remove a Foley Catheter
Activity 2	Changing Bedding
Activity 3	Inserting and Removing A Breathing Tube
Activity 4	Patient Health History Review
Activity 5	Hooking Up A Cardiac Monitor
Activity 6	Drawing Blood Tubes
Activity 7	Passive Range of Motion Exercises
Activity 8	Turning and Positioning the Patient
Activity 9	Suctioning the Patient
Activity 10	Performing CPR
Activity 11	Inserting and Starting An IV
Activity 12	Bathing and Turning the Patient

Table 5.2: Participant MV, MIF, and PIF and One-sided Upper 95%/95% TL Across all Activities

	MV	MIF	PIF	MV	MIF	PIF
	Mean $\pm$ Sd	Mean $\pm$ Sd	Mean $\pm$ Sd	TL_{95,95} K=2.736	TL_{95,95} K=2.736	TL_{95,95} K=2.736
Participant 1	23.1 $\pm$ 4.0	59.8 $\pm$ 10.6	96.5 $\pm$ 21.4	34.1	88.8	154.9
Participant 2	16.3 $\pm$ 2.3	40.6 $\pm$ 5.0	65.0 $\pm$ 13.0	22.5	54.2	100.6
Participant 3	13.7 $\pm$ 2.1	43.2 $\pm$ 8.3	77.9 $\pm$ 16.5	19.4	66.0	123.0
Participant 4	20.3 $\pm$ 5.0	47.8 $\pm$ 7.5	91.2 $\pm$ 14.9	34.0	68.3	132.0
Participant 5	14.8 $\pm$ 1.8	32.4 $\pm$ 4.7	69.2 $\pm$ 6.9	19.7	45.4	88.2
Participant 6	24.2 $\pm$ 2.9	54.0 $\pm$ 6.9	89.7 $\pm$ 15.9	32.2	72.9	133.2
Participant 7	20.4 $\pm$ 3.3	52.6 $\pm$ 6.1	84.1 $\pm$ 16.7	29.5	69.1	129.9
Participant 8	23.2 $\pm$ 3.9	55.9 $\pm$ 6.7	87.9 $\pm$ 15.6	33.9	74.4	130.6
Participant 9	28.5 $\pm$ 4.7	63.9 $\pm$ 8.6	114.4 $\pm$ 16.0	41.5	87.3	158.2

Table 5.3: Participant 95% Confidence Intervals for MV, MIF, and PIF

	MV	MIF	PIF
	95 % CI	95 % CI	95 % CI
Participant 1	[21.8, 24.5]	[56.2, 63.4]	[89.2, 103.7]
Participant 2	[15.5, 17.1]	[38.9, 42.2]	[60.6, 69.4]
Participant 3	[13.0, 14.4]	[40.4, 46.0]	[72.4, 83.5]
Participant 4	[18.6, 22.0]	[45.3, 50.3]	[86.2, 96.2]
Participant 5	[14.1, 15.4]	[30.8, 34.0]	[66.9, 71.6]
Participant 6	[23.3, 25.2]	[51.7, 56.3]	[84.3, 95.1]
Participant 7	[19.2, 21.5]	[50.5, 54.6]	[78.5, 89.8]
Participant 8	[21.8, 24.5]	[53.6, 58.2]	[82.6, 93.2]
Participant 9	[26.9, 30.1]	[61.0, 66.8]	[108.9, 119.8]

An analysis of variance revealed that at a significance level of $\alpha = 0.05$, participant does have a significant effect on MV, MIF, P.I.F. The following tables summarize the results of a post hoc Tukey HSD tests performed on the effect of participant (Table 5.4, Table 5.5, and Table 5.6).

Table 5.4: Tukey HSD Participant: MV

Participant #		LS Mean
Participant 9	A	28.5
Participant 6	B	24.2
Participant 8	B	23.2
Participant 1	B	23.1
Participant 7	C	20.4
Participant 4	C	20.3
Participant 2	D	16.3
Participant 5	D E	14.8
Participant 3	E	13.7
Levels not connected by same letter are significantly different $\alpha=0.05$		

Table 5.5: Tukey HSD Participant: MIF

Participant #		LS Mean
Participant 9	A	63.9
Participant 1	A B	59.8
Participant 8	B C	55.9
Participant 6	C	54.0
Participant 7	C D	52.6
Participant 4	D E	47.8
Participant 3	E F	43.2
Participant 2	F	40.6
Participant 5	G	32.4
Levels not connected by same letter are significantly different $\alpha=0.05$		

Table 5.6: Tukey HSD Participant: PIF

Participant #		LS Mean
Participant 9	A	114.4
Participant 1	B	96.5
Participant 4	B C	91.2
Participant 6	B C	89.7
Participant 8	B C D	87.9
Participant 7	C D	84.1
Participant 3	D E	77.9
Participant 5	E F	69.2
Participant 2	F	65.0
Levels not connected by same letter are significantly different $\alpha=0.05$		

The average MV, MIF, and PIF across all participants for each activity was calculated and an analysis of variance was performed. The average values for each activity are summarized in Table 5.7 the upper 95-95% tolerance limits are also recorded. The 95% confidence intervals for each activity are shown in Table 5.8.

Table 5.7: Activity MV, MIF, and PIF and One-sided Upper 95%/95% TL Across all Activities

	MV	MIF	PIF	MV	MIF	PIF
	Mean $\pm$ Sd	Mean $\pm$ Sd	Mean $\pm$ Sd	TL _{95,95} K=3.031	TL _{95,95} K=3.031	TL _{95,95} K=3.031
Activity 1	19.0 $\pm$ 5.2	46.6 $\pm$ 10.8	76.3 $\pm$ 17.5	34.8	79.3	129.2
Activity 2	22.6 $\pm$ 5.7	53.9 $\pm$ 11.1	90.5 $\pm$ 16.4	39.8	87.6	140.1
Activity 3	19.5 $\pm$ 4.8	47.8 $\pm$ 10.2	81.0 $\pm$ 16.0	34.2	78.6	129.5
Activity 4	15.9 $\pm$ 3.2	48.7 $\pm$ 11.6	110.3 $\pm$ 26.9	25.6	83.9	191.7
Activity 5	19.6 $\pm$ 4.7	48.0 $\pm$ 9.9	80.1 $\pm$ 16.5	33.7	77.9	130.2
Activity 6	17.8 $\pm$ 4.0	43.4 $\pm$ 8.6	73.4 $\pm$ 12.8	29.9	69.4	112.2
Activity 7	20.3 $\pm$ 5.8	49.5 $\pm$ 12.0	81.2 $\pm$ 18.1	37.9	85.8	136.2
Activity 8	23.9 $\pm$ 7.1	52.8 $\pm$ 15.3	92.8 $\pm$ 20.8	45.5	99.1	155.9
Activity 9	20.1 $\pm$ 5.2	48.8 $\pm$ 11.7	81.3 $\pm$ 14.7	35.8	84.2	125.9
Activity 10	25.4 $\pm$ 5.2	59.2 $\pm$ 10.4	102.6 $\pm$ 18.8	41.3	90.7	159.5
Activity 11	20.0 $\pm$ 5.8	49.2 $\pm$ 12.8	80.0 $\pm$ 18.9	37.6	88.0	137.2
Activity 12	21.8 $\pm$ 5.6	52.1 $\pm$ 11.7	85.1 $\pm$ 18.2	38.7	87.7	140.2

Table 5.8: Activity 95% Confidence Intervals for MV, MIF, and PIF

	MV	MIF	PIF
	95 % CI	95 % CI	95 % CI
Activity 1	[17.0, 21.1]	[42.4, 50.9]	[69.4, 83.2]
Activity 2	[20.4, 24.8]	[49.5, 58.3]	[84.0, 97.0]
Activity 3	[17.6, 21.4]	[43.8, 51.8]	[74.6, 87.3]
Activity 4	[14.6, 17.2]	[44.1, 53.3]	[99.7, 120.9]
Activity 5	[17.7, 21.4]	[44.1, 51.9]	[73.5, 86.6]
Activity 6	[16.2, 19.4]	[40.0, 46.8]	[68.4, 78.5]
Activity 7	[18.0, 22.6]	[44.7, 54.2]	[74.1, 88.4]
Activity 8	[21.1, 26.7]	[46.8, 58.9]	[84.5, 101.0]
Activity 9	[18.1, 22.2]	[44.2, 53.5]	[75.5, 87.1]
Activity 10	[23.4, 27.5]	[55.1, 63.3]	[95.1, 110.0]
Activity 11	[17.7, 22.3]	[44.1, 54.2]	[72.6, 87.5]
Activity 12	[19.6, 24.0]	[47.5, 56.8]	[77.9, 92.3]

The analysis of variance revealed activity does have a significant effect on MV, MIF, and PIF. Post hoc Tukey tests revealed that some activities did not have a significant effect when compared to others. The results of the post hoc Tukey tests are summarized below in Table 5.9, Table 5.10, and Table 5.11. It maybe intuitive to conclude that activity 10, performing C.P.R., would be significantly different from the other activities since it has the highest MV and MIF.

However, the Tukey tests revealed that MV for activity 10 was not significantly different from activity 8, 2, or 12. Also MIF for activity 10 was not significantly different from activity 2, 7, 8, 11, 12. It should also be noted that the upper 95%/95% tolerance limit for the PIF of activity 4, reviewing patient health history was 192 L/min. This can most likely be attributed to the effect of speech on peak inspiratory flows.

Table 5.9 Tukey HSD Activity: MV

Activity #		LS Mean
Activity 10	A	25.4
Activity 8	A B	23.9
Activity 2	A B C	22.6
Activity 12	A B C D	21.8
Activity 7	B C D E	20.3
Activity 9	B C D E	20.1
Activity 11	B C D E	20.0
Activity 5	B C D E	19.6
Activity 3	B C D E	19.5
Activity 1	C D E	19.0
Activity 6	D E	17.8
Activity 4	E	15.9
Levels not connected by same letter are significantly different $\alpha=0.05$		

Table 5.10 Tukey HSD Activity: MIF

Activity #		LS Mean
Activity 10	A	59.2
Activity 2	A B	53.9
Activity 8	A B C	52.8
Activity 12	A B C	52.1
Activity 7	A B C	49.5
Activity 11	A B C	49.2
Activity 9	B C	48.8
Activity 4	B C	48.7
Activity 5	B C	48.0
Activity 3	B C	47.8
Activity 1	B C	46.6
Activity 6	C	43.4
Levels not connected by same letter are significantly different $\alpha=0.05$		

Table 5.11: Tukey HSD Activity: PIF

Activity #		LS Mean
Activity 4	A	110.3
Activity 10	A B	102.6
Activity 8	B C	92.8
Activity 2	B C D	90.5
Activity 12	C D E	85.1
Activity 9	C D E	81.3
Activity 7	C D E	81.2
Activity 3	C D E	81.0
Activity 5	C D E	80.1
Activity 11	C D E	80.0
Activity 1	D E	76.3
Activity 6	E	73.4
Levels not connected by same letter are significantly different $\alpha=0.05$		

Three two sample t-tests were performed on MV, MIF and PIF by gender and found that gender also has a significant effect. The t-test results are summarized below in Table 5.12

Table 5.12: Gender t-test Results					
MV: M-F t-test Results		MIF: M-F t-test Results		PIF: M-F t-test Results	
Male (Mean $\pm$ SD)	24.1 $\pm$ 5.1	Male (Mean $\pm$ SD)	55.4 $\pm$ 9.4	Male (Mean $\pm$ SD)	95.8 $\pm$ 18.9
Female (Mean $\pm$ SD)	17.7 $\pm$ 4.5	Female (Mean $\pm$ SD)	45.8 $\pm$ 12.0	Female (Mean $\pm$ SD)	77.8 $\pm$ 18.3
Confidence Level	0.95	Confidence Level	0.95	Confidence Level	0.95
Prob > t	<.0001	Prob > t	<.0001	Prob > t	<.0001

Additional study results such as the 75th, 50th percentile, activity times, and the total volume inhaled are reported in the appendix of this report.

6 Conclusions and Limitations

A significant limitation of this study was the relatively small sample size of nine participants. Also, this study did not include any physicians. Physicians would be performing significantly different patient care activities. Another factor that should be considered is that only three participants talked during the patient care activities, it can be inferred that in an actual health care setting communication will be more frequent. Multiple studies have concluded that speech significantly increases peak inhalation flow, thus it is imperative that the effect of speech and non-speech conditions be examined further. It is also important to consider all physical attributes of the subjects, such as weight, height and BMI. Further analysis will be needed to include these effects.

The objective of this study was to characterize the breathing flow rates of health care workers performing patient care activities, to determine the feasibility of lowering the required minimum operational flow rate of PAPRs. The results of this study confirmed that, breathing flow characteristics are affected by individual, gender, and type of activity.

The main variable to consider, for assessing the feasibility of lowering the minimum operational flow rates of PAPRs is peak inhalation flow. Suppose the user's peak inhalation flow rate exceeds the PAPRs airflow delivery rate. In that case, a negative pressure environment can be created, and airborne contaminants can be drawn into the mask or hood. This research demonstrated that the peak inhalation flows of certain patient care activities were significantly higher than others. Performing CPR and patient health history review had the highest peak inhalation flows, 102.6 ± 18.8 , 110.3 ± 26.9 , respectively. The high peak inhalation flow values for performing CPR can be attributed to the high physiological demand of the activity.

In contrast, the high peak inhalation flow for reviewing the patient health history can be attributed to the effect of speech on inspiratory flow. It is well documented that speech significantly increases inspiratory flows. Nevertheless, future research should examine the effect of different speech variables such as amplitude, intensity, and duration. Also, additional research is needed regarding the duration of peak inspiratory flow spikes. For peak inhalation flow to affect the PAPRs protection level, the peak inhalation flow must exceed the PAPRS airflow delivery rate plus the dead volume inside the facepiece, hood, or helmet. So, the time duration of peak inspiratory flow spikes is vitally important.

With such a small sample size and wide range of peak inspiratory flows, further research is needed. This study indicated that the peak inhalation flow for certain activities was not significantly different from other activities. Thus, to simplify future research, certain activities could be omitted. The activities may be limited to reviewing the patients' health history, performing CPR, bathing and turning the patient, changing the bedding, and inserting and removing a foley catheter. The participants physical parameters are also important to consider for future research, the participant with the highest MV, PIF, and MIF also had the highest weight. To incorporate the highest inspiratory flows into future research, physical conditioning should be considered when selecting participants. Future subjects should be selected from a wide range of age, weight, body mass index, and levels of physical fitness if possible.

Due to the small sampling size, variability across participants, and the need for additional analysis the feasibility of lowering the minimum operational flow of PAPR remains inconclusive. However, these findings, combined with previous studies, provide crucial insight into healthcare workers' respiratory flow characteristics.

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Appendix:

Appendix A: Additional Study Results

Appendix B: Additional Respiratory Flow Graphs

Appendix B: Participant Fit Test Results

Appendix A: Additional Study Results:

Participant Summary 1 (Across All Activities)

Average MIF:	-59.81
SD Mif	10.60
Average 50th Percentile:	-60.63
50th Percentile SD:	17.02
Average 75th Percentile:	-79.91
75th Percentile SD:	16.33
Average Minute Volume:	23.12
Minute Volume SD	4.01
Average Activity Time	02:26
Average Inhalation time:	00:57
Average Volume Inhalaed:	-56.06
Total Volume Inhaled:	-2018.32
Total Time Sampled:	1:27:50

Participant Information:

Participan	1
Age:	23
Sex:	F
Height:	73
Weight:	160

Participant 2 Summary (Across All Activities)

Average MIF:	-40.55
SD Mif	4.99
Average 50th Percentile:	-45.61
50th Percentile SD:	5.05
Average 75th Percentile:	-55.06
75th Percentile SD:	8.19
Average Minute Volume:	16.31
Minute Volume SD	2.26
Average Activity Time	03:03
Average Inhalation time:	01:15
Average Volume Inhalaed:	-49.58
Total Volume Inhaled:	-1784.90
Total Time Sampled:	1:49:42

Participant Information:

Participan	2
Age:	23
Sex:	F
Height:	66
Weight:	131

Participant 3 Summary (Across All Activities)

Average MIF:	-43.18
SD Mif	8.34
Average 50th Percentile:	-44.33
50th Percentile SD:	8.74
Average 75th Percentile:	-58.96
75th Percentile SD:	13.59
Average Minute Volume:	13.72
Minute Volume SD	2.08
Average Activity Time	02:27
Average Inhalation time:	00:50
Average Volume Inhaled:	-34.24
Total Volume Inhaled:	-1232.52
Total Time Sampled:	1:28:27

Participant Information:

Participant #:	3
Age:	27
Sex:	F
Height:	66
Weight:	131

Participant 4 Summary (Across All Activities)

Average MIF:	-47.81
SD Mif	7.48
Average 50th Percentile:	-47.11
50th Percentile SD:	10.70
Average 75th Percentile:	-70.91
75th Percentile SD:	11.08
Average Minute Volume:	20.27
Minute Volume SD	5.00
Average Activity Time	02:14
Average Inhalation time:	00:56
Average Volume Inhaled:	-43.87
Total Volume Inhaled:	-1579.23
Total Time Sampled:	1:20:21

Participant Information:

Participant	4
Age:	29
Sex:	M
Height:	71
Weight:	200

Participant 5 Summary (Across All Activites)

Average MIF:	-32.41
SD Mif	4.75
Average 50th Percentile:	-29.92
50th Percentile SD:	9.14
Average 75th Percentile:	-51.51
75th Percentile SD:	6.42
Average Minute Volume:	14.76
Minute Volume SD	1.82
Average Activity Time	02:42
Average Inhalation time:	01:15
Average Volume Inhalaed:	-39.64
Total Volume Inhaled:	-1426.90
Total Time Sampled:	1:36:55

Participant Information:

Participan	5
Age:	26
Sex:	F
Height:	67
Weight:	140

Participant 6 Summary (Across All Activites)

Average MIF:	-54.00
SD Mif	6.90
Average 50th Percentile:	-57.47
50th Percentile SD:	7.09
Average 75th Percentile:	-73.98
75th Percentile SD:	10.74
Average Minute Volume:	24.25
Minute Volume SD	2.91
Average Activity Time	02:10
Average Inhalation time:	01:01
Average Volume Inhalaed:	-52.92
Total Volume Inhaled:	-1905.02
Total Time Sampled:	1:17:47

Participant Information:

Participan	6
Age:	26
Sex:	M
Height:	72
Weight:	198

Participant 7 Summary (Across All Activites)

Average MIF:	-52.58
SD Mif	6.06
Average 50th Percentile:	-55.60
50th Percentile SD:	5.69
Average 75th Percentile:	-68.92
75th Percentile SD:	11.62
Average Minute Volume:	20.37
Minute Volume SD	3.33
Average Activity Time	02:19
Average Inhalation time:	00:53
Average Volume Inhalaed:	-46.78
Total Volume Inhaled:	-1684.22
Total Time Sampled:	1:23:36

Participant Information:

Participant #:	7
Age:	24
Sex:	F
Height:	64
Weight:	125

Participant Summary 8 (Across All Activites)

Average MIF:	-55.90
SD Mif	6.75
Average 50th Percentile:	-60.46
50th Percentile SD:	11.47
Average 75th Percentile:	-75.36
75th Percentile SD:	10.28
Average Minute Volume	23.16
Minute Volume SD	3.91
Average Activity Time	02:39
Average Inhalation time:	01:07
Average Volume Inhalae	-61.08
Total Volume Inhaled:	-2198.89
Total Time Sampled:	1:35:21

Participant Information:

Participant #:	8
Age:	35
Sex:	M
Height:	75
Weight:	185

Participant 9 Summary (Across All Activites)

Average MIF:	-63.87
SD Mif	8.56
Average 50th Percentile:	-64.56
50th Percentile SD:	17.70
Average 75th Percentile:	-92.99
75th Percentile SD:	11.61
Average Minute Volume:	28.54
Minute Volume SD	4.75
Average Activity Time	02:21
Average Inhalation time:	01:01
Average Volume Inhalaed:	-65.37
Total Volume Inhaled:	-2353.36
Total Time Sampled:	1:24:53

Participant Information:

Participan	9
Age:	41
Sex:	M
Height:	75
Weight:	250

Least Squares Fit

Response MIF

Whole Model

Activity

Actual by Predicted Plot

Leverage Plot

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Activity	11	11	4867.3434	3.3770	0.0002*

LSMeans Differences Tukey HSD

$\alpha = 0.050$ $Q = 3.29312$

		LSMean[j]											
		1	2	3	4	5	6	7	8	9	10	11	12
LSMean[i]	Mean[i]-Mean[j]	0	-7.2379	-1.1757	-2.0761	-1.3654	3.23725	-2.8241	-6.1984	-2.2073	-12.586	-2.5429	-5.4982
	Std Err Dif	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	Lower CL Dif	0	-17.497	-11.435	-12.336	-11.625	-7.0222	-13.084	-16.458	-12.467	-22.845	-12.802	-15.758
	Upper CL Dif	0	3.02159	9.08379	8.18336	8.894	13.4967	7.43536	4.06109	8.05217	-2.3262	7.71659	4.76128
	1	7.23786	0	6.06221	5.16177	5.87242	10.4751	4.41377	1.0395	5.03058	-5.3478	4.695	1.73969
	2	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	3	-3.0216	0	-4.1972	-5.0977	-4.387	0.21566	-5.8457	-9.22	-5.2289	-15.607	-5.5644	-8.5198
	4	17.4973	0	16.3217	15.4212	16.1319	20.7346	14.6732	11.2989	15.29	4.91164	14.9544	11.9991
	5	1.17565	-6.0622	0	-0.9004	-0.1898	4.4129	-1.6484	-5.0227	-1.0316	-11.41	-1.3672	-4.3225
	6	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	7	-9.0838	-16.322	0	-11.16	-10.449	-5.8465	-11.908	-15.282	-11.291	-21.669	-11.627	-14.582
	8	11.4351	4.19724	0	9.35902	10.0697	14.6724	8.61101	5.23674	9.22782	-1.1506	8.89234	5.93693
	9	2.07609	-5.1618	0.90043	0	0.71064	5.31334	-0.748	-4.1223	-0.1312	-10.51	-0.4668	-3.4221
	10	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	11	-8.1834	-15.421	-9.359	0	-9.5488	-4.9461	-11.007	-14.382	-10.391	-20.769	-10.726	-13.682
	12	12.3355	5.09767	11.1599	0	10.9701	15.5728	9.51144	6.13717	10.1283	-0.2501	9.79267	6.83736
LSMean[j]	1	3.11542	-5.8724	0.18979	-0.7106	0	4.60269	-1.4586	-4.8329	-0.8418	-11.22	-1.1774	-4.1327
	2	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	3	-8.894	-16.132	-10.07	-10.97	0	-5.6568	-11.718	-15.092	-11.101	-21.48	-11.437	-14.392
	4	11.6249	4.38703	10.4492	9.54881	0	14.8621	8.8008	5.42653	9.41761	-0.9608	9.08203	6.12672
	5	-3.2373	-10.475	-4.4129	-5.3133	-4.6027	0	-6.0613	-9.4356	-5.4445	-15.823	-5.7801	-8.7354
	6	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542
	7	-13.497	-20.735	-14.672	-15.573	-14.862	0	-16.321	-19.695	-15.704	-26.082	-16.04	-18.995
	8	7.0222	-0.2157	5.84654	4.94611	5.65675	0	4.19811	0.82384	4.81492	-5.635	4.47934	1.52403
	9	2.82409	-4.4138	1.64844	0.74801	1.45865	6.06134	0	-3.3743	0.61681	-9.7616	0.28123	-2.6741
	10	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542	3.11542
	11	-7.4354	-14.673	-8.611	-9.5114	-8.8008	-4.1981	0	-13.634	-9.6426	-20.021	-9.9782	-12.934
	12	13.0835	5.84568	11.9079	11.0075	11.7181	16.3208	0	6.88518	10.8763	0.49787	10.5407	7.58537
LSMean[i]	1	6.19836	-1.0395	5.02271	4.12228	4.83292	9.43561	3.37427	0	3.99108	-6.3873	3.6555	0.70019
	2	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542	3.11542
	3	-4.0611	-11.299	-5.2367	-6.1372	-5.4265	-0.8238	-6.8852	0	-6.2684	-16.647	-6.6039	-9.5593
	4	16.4578	9.21995	15.2822	14.3817	15.0924	19.6951	13.6337	0	14.2505	3.87214	13.915	10.9596
	5	2.20728	-5.0306	1.03163	0.13119	0.84183	5.44453	-0.6168	-3.9911	0	-10.378	-0.3356	-3.2909
	6	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542	3.11542
	7	-8.0522	-15.29	-9.2278	-10.128	-9.4176	-4.8149	-10.876	-14.251	0	-20.638	-10.595	-13.55
	8	12.4667	5.22887	11.2911	10.3906	11.1013	15.704	9.64263	6.26836	0	-0.1189	9.92387	6.96856
	9	12.5857	5.34781	11.41	10.5096	11.2202	15.8229	9.76158	6.38731	10.3784	0	10.0428	7.0875
	10	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542	3.11542
	11	2.32622	-4.9116	1.15057	0.25014	0.96078	5.56347	-0.4979	-3.8721	0.11895	0	-0.2166	-3.1719
	12	22.8451	15.6073	21.6695	20.769	21.4797	26.0824	20.021	16.6468	20.6378	0	20.3023	17.347
LSMean[j]	1	2.54286	4.695	1.36721	0.46677	1.17742	5.78011	0.2812	3.6555	0.33558	10.043	0	2.9553
	2	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0	3.11542
	3	-7.7166	-14.954	-8.8922	-9.7927	-9.082	-4.4793	-10.541	-13.915	-9.9239	-20.302	0	-13.215
	4	12.8023	5.56445	11.6267	10.7262	11.4369	16.0396	9.97822	6.60395	10.595	0.21664	0	7.30414
	5	5.49817	-1.7397	4.32252	3.42208	4.13273	8.73542	2.67408	-0.7002	3.29089	-7.0875	2.95531	0
	6	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	3.11542	0
	7	-4.7613	-11.999	-5.9369	-6.8374	-6.1267	-1.524	-7.5854	-10.96	-6.9686	-17.347	-7.3041	0
	8	15.7576	8.51976	14.582	13.6815	14.3922	18.9949	12.9335	9.55926	13.5503	3.17195	13.2148	0
	9												
	10												
	11												
	12												

Level	Sq Mean
10	A 59.225959
2	A B 53.878146
8	A B C 52.838649
12	A B C 52.138456
7	A B C 49.464379
11	A B C 49.183146
9	B C 48.847565
4	B C 48.716372
5	B C 48.005730
3	B C 47.815939
1	B C 46.640286
6	C 43.403036

Levels not connected by same letter are significantly different.

Least Squares Fit

Response PIF

Whole Model

Actual by Predicted Plot

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Activity	11	11	35747.020	9.7345	<.0001*

Activity

Leverage Plot

LSMeans Differences Tukey HSD

α = 0.050 Q = 3.29312

	LSMean[j]	1	2	3	4	5	6	7	8	9	10	11	12
Mean(j)-Mean(j)		1	2	3	4	5	6	7	8	9	10	11	12
Std Err Dif													
Lower CL Dif													
Upper CL Dif													
1													
			-14.189	-4.6988	-34.017	-3.7947	2.85348	-4.9507	-16.494	-5.047	-26.281	-3.74	-8.8364
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728
			-30.565	-21.075	-50.393	-20.171	-13.523	-21.327	-32.87	-21.423	-42.657	-20.116	-25.212
			2.18713	1.16772	-17.641	12.5813	19.2295	11.4254	-0.1178	11.329	-9.9052	12.636	7.53962
2													
			14.1889	0	9.4901	-19.828	10.3942	17.0424	9.23822	-2.305	9.14189	-12.092	10.4488
			4.9728	0	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728
			-2.1871	0	-6.8859	-36.204	-5.9818	0.66635	-7.1378	-18.681	-7.2341	-28.468	-5.9272
			30.5649	0	25.8661	-3.4525	26.7702	33.4184	25.6142	14.0711	25.5179	4.2837	26.8249
3													
			4.69878	-9.4901	0	-29.319	0.90407	7.55226	-0.2519	-11.795	-0.3482	-21.582	0.98874
			4.9728	4.9728	0	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728
			-11.677	-25.866	0	-45.695	-15.472	-8.8238	-16.628	-28.171	-16.724	-37.958	-15.417
			21.0748	6.88591	0	-12.943	17.2801	23.9283	16.1241	4.58096	16.0278	-5.2064	17.3348
4													
			34.0174	19.8285	29.3186	0	30.2227	36.8708	29.0667	17.5235	28.9704	7.73616	30.2773
			4.9728	4.9728	4.9728	0	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728
			17.6413	3.45346	12.9426	0	13.8466	20.4948	12.6507	11.4751	12.5944	-8.6399	13.9013
			50.3934	36.2045	45.6946	0	46.5987	53.2469	45.4427	33.8995	45.3464	24.1122	46.6533
5													
			3.79471	-10.394	-0.9041	-30.223	0	6.64819	-1.1559	-12.699	-1.2523	-22.486	0.95467
			4.9728	4.9728	4.9728	4.9728	0	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728
			-12.581	-26.77	-17.28	-46.599	0	-9.7278	-17.532	-29.075	-17.628	-38.863	-16.321
			20.1707	5.98184	15.4719	-13.847	0	23.0242	15.2201	3.67689	15.1237	-6.1105	16.4307
6													
			-2.8535	-17.042	-7.5523	-36.871	-6.6482	0	-7.8041	-19.347	-7.9005	-29.135	-6.5935
			4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728	4.9728	4.9728	4.9728	4.9728
			-19.229	-33.418	-23.928	-53.247	-23.024	0	-24.18	-35.723	-24.276	-45.511	-22.97
			13.5225	-0.6663	8.82375	-20.495	9.72782	0	8.57188	-2.9713	8.47554	-12.759	9.7825
7													
			4.95066	-9.2382	0.25188	-29.067	1.15595	7.80414	0	-11.543	-0.0963	-21.331	1.21062
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728	4.9728	4.9728	4.9728
			-11.425	-25.614	-16.124	-45.443	-15.22	-8.5719	0	-27.919	-16.472	-37.707	-15.165
			21.3267	7.13779	16.6279	-12.691	17.532	24.1802	0	4.83284	16.2797	-4.9545	17.5866
8													
			16.4938	2.30495	11.7951	-17.534	12.6991	19.3475	11.5432	0	11.4468	-9.7874	12.7538
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728	4.9728	4.9728
			0.11782	-14.071	-4.581	-33.9	-3.6769	2.9713	-4.8328	0	-4.9292	-26.163	-3.6222
			32.8699	18.681	28.1711	-1.1475	29.0751	35.7233	27.9192	0	27.8229	6.58865	29.1298
9													
			5.04699	-9.1419	0.34821	-28.97	1.25228	7.90047	0.09633	-11.447	0	-21.234	1.30695
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728	4.9728
			-11.329	-25.518	-16.028	-45.346	-15.124	-8.4755	-16.28	-27.823	0	-37.61	-15.069
			21.423	7.23412	16.7242	-12.594	17.6283	24.2765	16.4723	4.92917	0	-4.8582	17.683
10													
			26.2812	12.0923	21.5824	-7.7362	22.4865	29.1347	21.3305	9.78737	21.2342	0	22.5412
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728
			9.90519	-4.2837	5.2064	-24.112	6.11048	12.7587	4.95453	-6.5887	4.85819	0	6.16515
			42.6572	28.4683	37.9584	8.63986	38.8625	45.5107	37.7066	26.1634	37.6102	0	38.9172
11													
			3.74004	-10.449	-0.9587	-30.277	-0.0547	6.59352	-1.2106	-12.754	-1.307	-22.541	0
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0	4.9728
			-12.636	-26.825	-17.335	-46.653	-16.431	-9.7825	-17.587	-29.13	-17.683	-38.917	-0.21472
			20.1161	5.92717	15.4173	-13.901	16.3213	22.9695	15.1654	3.62222	15.0691	-6.1651	0
12													
			8.8364	-5.3525	4.13762	-25.181	5.04169	11.6899	3.88574	-7.6574	3.78941	-17.445	5.09636
			4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	4.9728	0
			-7.5396	-21.729	-12.238	-41.557	-11.334	-4.6861	-12.49	-24.033	-12.587	-33.821	-11.28
			25.2124	11.0235	20.5136	-8.8049	21.4177	28.0659	20.2618	8.71858	20.1654	-1.0688	21.4724

Level	Sq Mean
4	A
10	A B
8	B C
2	B C D
12	C D E
9	C D E
7	C D E
3	C D E
5	C D E
11	C D E
1	D E
6	E

Levels not connected by same letter are significantly different.

Appendix B: Additional Respiratory Flow Data Graphs

Appendix C: Fit Test Results

FIT TEST REPORT

11/12/2020

ID NUMBER	01		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/12/2020 16:17	PORTACOUNT S/N	8038102806
DUE DATE	11/12/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

Rectangular Snap

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	5547	Y
DEEP BREATHING	64	2532	Y
HEAD SIDE TO SIDE	64	2935	Y
HEAD UP AND DOWN	64	9463	Y
TALKING	64	1931	Y
GRIMACE	15	Excl.	
BENDING OVER	64	4360	Y
NORMAL BREATHING	64	7571	Y
OVERALL FF		3682	Y

FIT TEST REPORT

11/16/2020

ID NUMBER	02		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	Rectangular Snip
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/16/2020 16:30	PORTACOUNT S/N	8038102806
DUE DATE	11/16/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	SM	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	7698	Y
DEEP BREATHING	64	2912	Y
HEAD SIDE TO SIDE	64	5801	Y
HEAD UP AND DOWN	64	13680	Y
TALKING	64	5054	Y
GRIMACE	15	Excl.	
BENDING OVER	64	7391	Y
NORMAL BREATHING	64	3973	Y
OVERALL FF		5370	Y

FIT TEST REPORT

11/06/2020

ID NUMBER	08		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/6/2020 16:15	PORTACOUNT S/N	8038102806
DUE DATE	11/6/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	71887	Y
DEEP BREATHING	64	22301	Y
HEAD SIDE TO SIDE	64	16112	Y
HEAD UP AND DOWN	64	10976	Y
TALKING	64	1051	Y
GRIMACE	15	Excl.	
BENDING OVER	64	5351	Y
NORMAL BREATHING	64	2678	Y
OVERALL FF		4062	Y

FIT TEST REPORT

11/10/2020

ID NUMBER	06		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/10/2020 18:45	PORTACOUNT S/N	8038102806
DUE DATE	11/10/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	34978	Y
DEEP BREATHING	64	28400	Y
HEAD SIDE TO SIDE	64	68428	Y
HEAD UP AND DOWN	64	42805	Y
TALKING	64	914	Y
GRIMACE	15	Excl.	
BENDING OVER	64	29390	Y
NORMAL BREATHING	64	15268	Y
OVERALL FF		5405	Y

FIT TEST REPORT

11/03/2020

ID NUMBER	05		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/3/2020 19:07	PORTACOUNT S/N	8038102806
DUE DATE	11/3/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	12620	Y
DEEP BREATHING	64	10551	Y
HEAD SIDE TO SIDE	64	11270	Y
HEAD UP AND DOWN	64	154	Y
TALKING	64	5266	Y
GRIMACE	15	Excl.	
BENDING OVER	64	4681	Y
NORMAL BREATHING	64	7965	Y
OVERALL FF		963	Y

FIT TEST REPORT

11/11/2020

ID NUMBER	07		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/11/2020 16:12	PORTACOUNT S/N	8038102806
DUE DATE	11/11/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	SM	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	12844	Y
DEEP BREATHING	64	11122	Y
HEAD SIDE TO SIDE	64	9852	Y
HEAD UP AND DOWN	64	703	Y
TALKING	64	3541	Y
GRIMACE	15	Excl.	
BENDING OVER	64	6547	Y
NORMAL BREATHING	64	7789	Y
OVERALL FF		3104	Y

FIT TEST REPORT

11/04/2020

ID NUMBER	04		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/4/2020 16:35	PORTACOUNT S/N	8038102806
DUE DATE	11/4/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	11750	Y
DEEP BREATHING	64	4729	Y
HEAD SIDE TO SIDE	64	6066	Y
HEAD UP AND DOWN	64	3050	Y
TALKING	64	1872	Y
GRIMACE	15	Excl.	
BENDING OVER	64	3752	Y
NORMAL BREATHING	64	10761	Y
OVERALL FF		4160	Y

FIT TEST REPORT

11/13/2020

ID NUMBER	09		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/13/2020 19:25	PORTACOUNT S/N	8038102808
DUE DATE	11/13/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	L	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	533	Y
DEEP BREATHING	64	1010	Y
HEAD SIDE TO SIDE	64	1824	Y
HEAD UP AND DOWN	64	3491	Y
TALKING	64	1585	Y
GRIMACE	15	Excl.	
BENDING OVER	64	1533	Y
NORMAL BREATHING	64	957	Y
OVERALL FF		1161	Y

FIT TEST REPORT

11/03/2020

ID NUMBER	03		
LAST NAME		CUSTOM1	
FIRST NAME		CUSTOM2	
COMPANY	WVU	CUSTOM3	
LOCATION	WV STEPS SIM 2	CUSTOM4	
TEST DATE	11/3/2020 16:31	PORTACOUNT S/N	8038102806
DUE DATE	11/3/2021	N95 COMPANION	N
RESPIRATOR	SUNDSTROM SR 100 HALFMASK [100]	PROTOCOL	OSHA 29CFR1910.134
MANUFACTURER	SUNDSTROM	PASS LEVEL	100
MODEL	SR 100		
MASK STYLE	HALFMASK	APPROVAL	
MASK SIZE	SM	EFFICIENCY<99%	False

<u>EXERCISE</u>	<u>DURATION (sec.)</u>	<u>FIT FACTOR</u>	<u>PASS</u>
NORMAL BREATHING	64	12049	Y
DEEP BREATHING	64	13313	Y
HEAD SIDE TO SIDE	64	17214	Y
HEAD UP AND DOWN	64	26427	Y
TALKING	64	13951	Y
GRIMACE	15	Excl.	
BENDING OVER	64	66053	Y
NORMAL BREATHING	64	23914	Y
OVERALL FF		18293	Y