



Study of Breathing-Related Metrics During Light Physical Activity

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Abstract

The worldwide outbreak of the COVID-19 pandemic in 2020 has changed many social aspects of human behaviors. This new situation gave high significance to the concerning question and the everlasting debate about the influence of wearing facial masks on critical vital signs. This study aimed to non-invasively explore the effect of wearing of the N95 facemask on physiological breathing-related measurements during daily activities. Short physical exercise protocols were developed to mimic daily activities (i.e., walking, climbing stairs, etc.) in terms of exercise intensity and duration in a consistent and controlled manner. The effect of wearing the N95 on breathing force and frequency, SPO2 and heart rates were measured at rest and during physical activities (i.e., pedaling on a stationary bicycle). Thirty-two subjects performed a total of four experimental setups to investigate the effect of two factors: N95 mask and physical activity. The main finding of this study is the significant increase in peak-to-peak breathing force (i.e., Differential Breathing Force (DBF)) exerted by chest muscles in response to wearing an N95 mask at rest and during physical activity ($p < 0.003$ and $p < 0.0003$, respectively). Moreover, a significant slight SPO2 decrease was recorded during physical activity with N95 compared to non-mask ($p < 0.0003$). The proposed method of quantitatively measuring breathing forces via a breathing belt was a noninvasive, reliable way of confirming the negative impact of using N95 masks on breathing, especially during physical activities.

Keywords: breathing force; breathing frequency; heart rate; oxygen level; COVID-19; physical activity

INTRODUCTION

Since the beginning of 2020, people around the globe have been following precautionary guidelines issued by the World Health Organization (WHO) to control the Coronavirus 2019 (COVID-19) spread [1]. Wearing a facemask was the primary precautionary guideline to control the infection of this virus [2]. Such a precautionary measure is not convenient for some people, as CO2 exhalation from the human body gets limited and can lead to respiratory discomfort, tachycardia symptoms, and dizziness [3]. Moreover, facemasks also increase the humidity of inspired air, increase body temperature, and cause facial skin problems [3].

Wearing N95 masks has been reported in the literature to affect vital signs related to the respiratory system (breathing, airflow, heart rate, blood pressure, oxygen saturation, cardiac output, and total peripheral resistance) 4. Breathing difficulty is the most common feeling while wearing a face mask, especially during activities. If the person suffers from chronic respiratory

disease, such an impact may be greater, which is a growing global health and economic issue affecting more than 435 million globally [5, 6].

The literature is rich with many valuable studies that have investigated the influence of wearing N95 facemasks on cardiopulmonary-related vital signs for different populations and under different experimental setups and conditions. Jung-Hyun Kim et al. [7] studied the effect of wearing an N95 mask on cardiovascular and pulmonary responses associated with postural and exercise in pregnant and non-pregnant women. In their study, they addressed heart rate, blood pressure, mean arterial pressure, total peripheral resistance, stroke volume, cardiac output, oxygen saturation, transcutaneous carbon dioxide, and fetal heart rate. The responses were measured for one hour of daily sitting, standing, and moderate exercise (bicycle ergometer) activities with and without wearing N95 facemasks. Shenal, Brian V. et al. [8] studied the effect of prolonged wearing of an N95 facemask (8 hr) on the discomfort magnitude and exertion level experienced by 27 healthcare workers during their occupational duties. The discomfort levels and exertion were self-determined by each subject before doffing the mask using a visual analog scale and a Borg scale, respectively. Li, Y. et al. [9] studied the effect of wearing N95 and surgical facemasks on thermo physiological responses and the subjective perception of the discomfort of 10 subject's performing intermittent exercise on a treadmill.

In another study, Raymond J. Roberge et al. [10] investigated the physiological impact of the N95 filtering face piece respirator on 10 healthcare workers conducting treadmill walking sessions at different speeds. They monitored heart rate, respiratory rate, tidal volume, minute volume, blood oxygen saturation, PCO₂, and user comfort and exertion with and without an N95 mask. Dacha, Sauwaluk, et al. [11] investigated the impact of wearing different types of facemasks, including N95, when performing six-minute walking tests on respiratory symptoms using spirometry (dyspnea and breathing effort), oxygen saturation, and functional capacity. Tong, Pearl Shuang Ye, et al. [12] also investigated the respiratory consequences of using N95 masks during low-intensity work by pregnant healthcare workers.

Do Prado, Danilo Marcelo Leite et al. [13] review the findings of a collection of studies on the effects of N95 facemask on exercise tolerance and cardiorespiratory responses under different conditions. They pointed out different findings of the studies in the literature. In a similar review, Hopkins, Susan R. et al. [14] concluded that wearing the N95 facemask during physical activity mainly increases dyspnea, with small effects on other physiological parameters. These review papers indicated the great concern and interest in investigating the effect of wearing N95 facemasks on the vital signs of the heart and breathing. However, there were differences between their results and conclusions, which may be attributed to different experimental settings or how the experiment was carried out. Moreover, none of the mentioned works have objectively and directly measured the effect of wearing an N95 mask on mechanical breathing force exerted by chest muscles during controlled physical activity. This parameter may directly reflect the extent of such an effect if any.

This study applied a breathing belt, SPO₂ finger sensor, and a stationary cycle to investigate the impact of wearing N95 facemasks on breathing force and breathing frequency (BF), heart rate (HR), and SPO₂ during normal daily activities by simulating these activities in a controlled manner. The resting (sitting on a chair) and physically active states (pedaling on a stationary

cycle) were applied to mimic daily activities (i.e., walking, climbing stairs, etc.) in terms of exercise intensity and duration.

MATERIAL AND METHODS

All Experiments were performed at the Biomedical Technology Department laboratories at King Saud University, Riyadh, Saudi Arabia. Thirty-two subjects participated in the experiments. Experimental data were collected from all subjects using the software of the measuring sensor, digitally processed using MATLAB (The Math Works, Inc. MATLAB. Version R2021a), and statistically analyzed using MICROSOFT Excel (2019).

Participants

Thirty-two subjects participated in this study. None of the participants had any medical history related to breathing or heart conditions. The participants' age ranged from 20 to 36 years with a mean of 23.7 ± 4.9 SD years. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by Institutional Review Board (IRB) at King Saud University (E-22-6650).

Measurement Sensors

The breathing force and breathing frequency (BF) were measured using a Respiration Belt "Vernier, Go Direct" The belt used a force sensor and an adjustable strap around the chest. Data from the belt were transferred to the computer via Bluetooth connection and read by the data acquisition software provided by the belt manufacturer. The heart rate (HR) and SPO₂ were measured using a fingertip SPO₂ sensor (Oxysmart, PC-60FW), and readings were manually registered every 1 min. The exercise protocol was performed using a stationary bike with adjustable speed and resistance.

Experimental Setup and Protocol

The respiration belt was placed around the subject's chest at the beginning of each experiment, approximately at the "xiphoid process" level. The SPO₂ finger sensor was placed on the right-hand index finger. Each experiment included four activities that lasted for 5 min each, with 5 min breaks between consecutive activities.

Each participant performed a total of four protocols. The first and second protocols were in sedentary upright restful conditions (mask-free (RF), then with N95 mask (RN)), and the third and the fourth protocols were in physically active conditions, pedaling on the stationary bicycle (mask-free (AF), then with an N95 mask (AN)). The pedaling resistance was fixed at a specific value, and pedaling revolution was continuously controlled by the subject at around 45 RMP.

Data Analysis

The measured breathing force data were transferred to the computer via Bluetooth connection and read by Vernier data acquisition software. Then, they were imported into MATLAB (The Math Works, Inc. MATLAB. Version R2021a) for further processing. The sampling frequency of the respiration belt was 10 sample/sec.

Local maxima in each breathing cycle were identified to find the maximum force exerted by chest muscle during inhalation. For each activity, the overall maximum force was determined

by averaging all local maxima for each participant. Similarly, the minimum force was identified during exhalation, and the overall minimum force was calculated. I defined the term Differential Breathing Force (DBF) as the peak-to-peak value of the breathing force, i.e., the difference between maximum force and minimum force, to compare the measured breathing force for all subjects. Hence, I calculated the average DBF for each experimental protocol (i.e., DBFRF, DBFRN, DBFAF, and DBFAN) for each subject. The impact of wearing the N95 mask on the DBF of any subject in rest and physical activity protocols is presented as the ratio DBFRN/DBFRF and DBFAN/DBFAF for that subject, respectively. The overall impact of wearing the N95 mask on all subjects is defined as the averaged ratios of all 32 subjects:

$$\text{For rest protocols: DBF ratio}_{(rest)} = \frac{\sum_{i=1}^{32} \left(\frac{\text{DBF}_{RN}}{\text{DBF}_{RF}} \right)_i}{32}$$

$$\text{For physical activity protocols: DBF ratio}_{(active)} = \frac{\sum_{i=1}^{32} \left(\frac{\text{DBF}_{AN}}{\text{DBF}_{AF}} \right)_i}{32}$$

The average BF in each of the experimental protocols was calculated for each subject using the number of local maxima and minima during the protocol (Figure 1). Hence, four values of the average BF were obtained for each subject, corresponding to the four protocols performed by each subject (namely: RF, RN, AF, and AN).

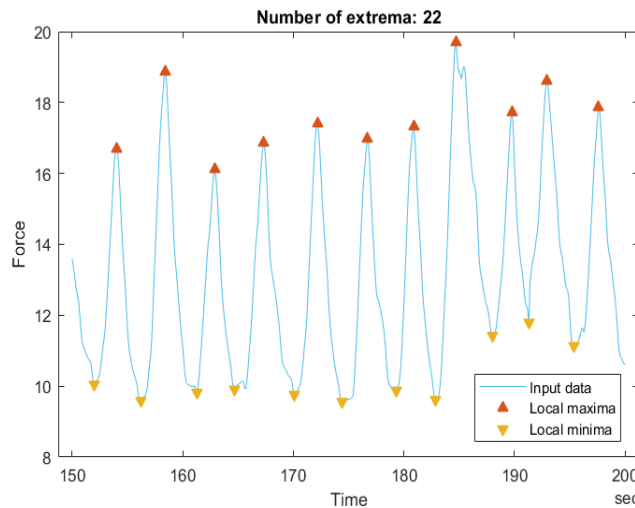


Figure 1 Breathing force oscillation with inhalation and exhalation over the interval of 200 sec. Breathing frequency (BF) was calculated according to the number of local maxima and minima.

The measured values corresponding to RF and RN activities were statistically analyzed using MICROSOFT Excel (2019) statistical package (t-Test: Paired Two Sample for Means) to deduce if wearing an N95 mask had any significant impact on the differential breathing force or frequency. Similarly, the measured values corresponding to AF and AN were also statistically analyzed using the same approach.

SPO2 and HR were measured at the start of each activity and then every minute during each of the four activities performed by each subject. These values were averaged for each activity and statistically analyzed using the same approach mentioned above.

RESULTS

Breathing Frequency and Heart Rate

Table 1 shows BF and HR (mean±SD) values for all 32 subjects during the four activities (RF, RN, AF, and AN). The results show that during resting, wearing N95 did not cause any significant change in BF ($p = 0.175$) or HR ($p = 0.223$) compared to mask-free. A similar result was obtained during physical activities, so there was no significant change in BF ($p = 0.258$) or HR ($p = 0.483$) in response to wearing N95.

Table 1. The breathing frequency and heart rate for all 32 subjects during the four activities (RF, RN, AF, and AN) .

	Rest		Active	
	RF	RN	AF	AN
Breathing frequency (BF)	14.60 ± 4.52	15.03 ± 4.90	35.66 ± 13.72	35.02 ± 14.69
Heart Rate (HR)	79.13 ± 13.24	81.96 ± 22.81	119.19 ± 28.49	119.42 ± 18.63
<i>RF: rest mask-free, RN: rest with N95, AF: active mask-free, AN: active with N95. Values are mean±SD</i>				

The BF results for the physical activity protocol on the stationary bicycle are presented in Table 1. It was found that in comparison to resting, physical activities caused a significant 144.2% increase in BF without an N95 mask ($p < 2 \times 10^{-10}$), and a significant 133% increase in BF with N95 ($p < 4 \times 10^{-9}$). Similarly, physical activity caused a significant increase of 50.6% ($p < 8 \times 10^{-9}$) and 45.7% ($p < 7 \times 10^{-10}$) in HR without and with N95, respectively.

Breathing Force

The average DBF for each experimental protocol (i.e., DBFRF, DBFRN, DBFAF, and DBFAN) was calculated for each subject, as mentioned earlier. Similarly, the impacts of wearing the N95 mask on DBF were also calculated for all subjects individually in rest and physical activity protocols as the ratios DBFRN/DBFRF and DBFAN/DBFAF, respectively. Then, the average of these ratios of all 32 subjects was calculated to measure the overall impacts of wearing the N95 mask during rest and physical activities. Table 2 shows averaged values for all subjects of DBF (mean±SD) for the four protocols and the “DBF ratio” (mean±SD) for the rest and physical activity protocols. A significant increase in DBF was detected in response to wearing an N95 mask at rest ($p < 0.003$) and also during physical activities ($p < 0.0003$).

Table 2. DBF in rest and physically active protocols without and with N95 mask (RF, RN, AF and AN), and the ratio of DBF with N95 to that measured without N95.

	Rest		Active	
	RF	RN	AF	AN
DBF	5.32 ± 1.88	6.05 ± 2.06*	10.89 ± 6.37	12.89 ± 6.15*
DBF ratio	1.18 ± 0.29		1.24 ± 0.23	
RF: rest mask-free, RN: rest with N95, AF: active mask, AN: active with N95. (*) indicates a significant difference between mask-free and N95. Values are mean±SD. Force values in Newton.				

The results also indicated that the increase in DBF in response to wearing an N95 mask in the physical activity protocol was contributed by both a significant decrease in the minima ($p < 0.003$) and a significant increase in maxima ($p < 0.001$). Whereas in the rest protocol, the increase in BDF was mainly contributed by the significant increase in maxima ($p < 0.003$) without any significant decrease in minima ($p = 0.115$). Table 3 shows averaged values of maximum and minimum DBF (mean ± SD) for all subjects in the four experimental protocols. The results of the measured SPO2 show that wearing an N95 mask did not significantly impact SPO2 at rest. On the contrary, wearing an N95 mask during physical activities appeared to cause a slight but significant decrease in SPO2 ($p < 0.0003$).

Table 3. Averaged maximum and minimum DBF for all 32 subjects in the four experimental protocols

Protocol	Maximum DBF	Minimum DBF
RF	13.05 ± 3.39	7.73 ± 2.01
RN	13.65 ± 3.41*	7.59 ± 1.81
AF	20.61 ± 7.90	9.72 ± 4.64
AN	21.93 ± 7.45*	9.04 ± 4.28*
RF: rest mask-free, RN: rest with N95, AF: active mask, AN: active with N95. (*) indicates a significant difference between mask-free and N95. Values are mean±SD. Force values in Newton.		

Oxygen level

Table 4 shows averaged SPO2 (mean±SD) values for all subjects in the four experimental protocols.

Table 4 Averaged SPO2 (mean ± SD) values for all subjects in the four experimental protocols.

	Rest		Active	
	RF	RN	AF	AN
SPO ₂	98.38% ± 0.72	98.23% ± 0.82	98.13% ± 0.82	97.49% ± 0.83*
RF: rest mask-free, RN: rest with N95, AF: active mask, AN: active with N95. (*) indicates a significant difference between mask-free and N95. Values are mean±SD				

DISCUSSION

The COVID-19 pandemic in 2020 led to the historical global mandate of wearing a face mask, providing high significance to the concerning question about the influence of wearing facial

mask. This study shows increase in breathing frequency and heart rate in response to the controlled physical activity level, during pedaling on a stationary cycle, were 144.2% and 50.6%, respectively. The main finding of this study is that wearing an N95 mask either at rest or during physical activity significantly directly affects the mechanical breathing force exerted by chest muscles. This influence is reflected by the significant increase in the peak-to-peak breathing force (the DBF ratio was 1.18 ± 0.29 at rest and 1.24 ± 0.23 during physical activities). It is noticed DBF is increased with physical activity. In addition, the results of this study indicated a significant slight decrease in SPO2 during physical activity with N95 ($97.49\% \pm 0.83$), compared to that measured without N95 ($98\%.13 \pm 0.82$). Increase in force exerted during breathing, and lower SPO2 could be associated with the level of discomfort when wearing an N95 facemask. Li, Y. et al. [9] reported that N95 masks wearer scored low at preference test. In this study, physical activity duration was limited to 5 min. Longer and higher intensity physical activities is recommended to be investigated in future work for possible higher impact on force exerted by breathing muscles, SPO2 and heart rate. It was shown that discomfort and exertion due to wearing masks and respirator increased over time with continual use over an 8-hr period [8].

The results showed HR was increased as expected during exercise, with slight insignificant increase in HR when wearing N95 mask both at rest and during exercise. Similarly, it was reported by Jung-Hyun Kim et al. [7] that wearing N95 masks for 1 hour did not result in significant HR difference. Dacha, Sauwaluk, et al. [11] studied effects of wearing different facial masks on respiratory symptoms during six-minute walk test. Their results were consistent with my results in terms of the increased breathing effort due to N95 and no significant difference in HR. They reported lower but insignificant SPO2 results due to wearing N95 masks.

Different methodologies and experimental protocols applied in literature to address the impact of wearing an N95 mask on the critical cardiovascular and pulmonary vital signs of different populations. The common factor among these studies is the absence of direct measurement of the mechanical breathing force exerted by chest muscles. Subjective measurements of discomfort, level of exertion and dyspnea (Borg chart method) were used. Some studies reported significant increase in discomfort levels in response to wearing an N95 mask [8, 9]. In contrast, others reported significant increase in the level of exertion without any effect on dyspnea level [11]. Another study concluded that wearing an N95 mask had no impact on the discomfort level or the exertion level [10]. Different studies' conditions, experimental setups, and using subjective scales led to disagreement in breathing related results and findings due to wearing masks [13, 14].

CONCLUSION

This study applied a breathing belt, an SPO2 finger sensor, and a stationary cycle to non-invasively investigate the impact of wearing an N95 facemask on breathing force, frequency, HR, and SPO2 during normal physical activities in a controlled manner in rest and physically active states. The study concluded that wearing an N95 mask caused a significant increase in the peak-to-peak breathing force in the physically active and rest states. The study also finds that wearing an N95 mask during physical activities may result in a slight decrease in SPO2. This finding is in accordance with the recommendation of the WHO of not wearing the N95 mask during physical activities. The proposed method of quantitatively measuring breathing

forces via a breathing belt was a noninvasive, reliable way of confirming the negative impact of using an N95 mask on breathing-related measurement, during light physical activities.

Ethical Consideration

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by Institutional Review Board (IRB) at King Saud University (E-22-6650).

Data Availability Statement

The data used to support the findings of this study are included in the article.

Disclosure

The author reports no conflicts of interest in this work.

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