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Effects of Face Masks on Respiratory Performance: A Within-Subject Design Study †

Eng Keat Kwa and Poh Foong Lee *

Lee Kong Chian Faculty of Engineering and Science, University Tunku Abdul Rahman (Sungai Long Campus), Kajang 43000, Malaysia; kwaek6644@1utar.my

* Correspondence: leepf@utar.edu.my

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Abstract: There is an ongoing debate about whether wearing a facemask impacts respiratory performance, which is especially crucial in the prevention of COVID-19 transmission. This pre- and post-intervention within-subject design study aimed to quantify the impact of wearing a medical facemask during deep breathing on respiratory functions and compare it to deep breathing without a facemask. A total of 100 samples (n = 100) were obtained from a single healthy young male adult (age = 24 years) who underwent pulmonary function measurement before and after 5 min of deep breathing twice a day (morning and night) for 25 days without a facemask, followed by wearing a 4-ply medical face mask for the following 25 days. Significant improvements in all parameters (mean ± SD), including tidal volume (38.04 ± 46.97 mL, $p < 0.005$), vital capacity (34.08 ± 105.36 mL, $p = 0.027$), forced vital capacity (0.11 ± 0.11 L, $p < 0.005$), forced expiratory volume in 1 s (0.13 ± 0.13 L, $p < 0.005$), peak expiratory flow (0.36 ± 0.74 L/s, $p < 0.005$), and forced expiratory flow at 25–75% of forced vital capacity (0.04 ± 0.55 L/s, $p < 0.005$), were found without the facemask, whereas significant an improvement in forced expiratory volume in 1 s (0.05 ± 0.18 L, $p = 0.049$), a significant reduction in vital capacity (−29.98 ± 103.39 mL, $p = 0.046$), and no other significant changes were observed with the medical facemask. It was suggested that face masks exert breathing resistance but do not affect deep breathing performance. These results provide further knowledge of the effect of a facemask during deep breathing on respiratory performance.

Keywords: deep breathing; COVID-19; respiratory performance; mask; tidal volume

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1. Introduction

The mass outbreak of coronavirus disease 2019 (COVID-19) brought an epidemic to the majority of countries in the world. To prevent the further spread of the disease, many nations implemented lockdown strategies that extensively influenced daily life, communication, working, and economic systems [1]. Inevitably, it gave rise to the concern of issues related to lower physical health [2]. One of the most significant approaches, i.e., breathing exercises, has been proposed to improve undesirable conditions.

Deep breathing is involuntary respiration involving deep inhalation and exhalation in each regular respiratory cycle [3]. It has a long historical tradition in yoga, tai chi, and qigong [4,5]. Deep breathing has been well known for its ability to improve vagal tone and suppress the sympathetic nervous system, which aids in the regulation of system function and the alteration in parasympathetic activity [6], promoting individual physiological moderation and reduced stress levels [7]. In terms of respiratory moderation, sustained deep inhalation and exhalation continue to stimulate the dynamicity of lung volume and airflow [8]. This also suggests that the importance of pulmonary improvement on physical health and wellness. A pilot study showed that the pulmonary function of the healthy participants improved, particularly peak expiratory flow rate (PEFR) and forced

expiratory volume (FEV1), after 6 weeks of yogic breathing [4]. Additionally, a research result showed that 2 weeks of deep breathing significantly increased tidal volume (TV), forced vital capacity (FVC), and FEV1 among healthy participants [9]. Pramanik et al. [10] presented similar outcomes on FVC and FEV1 using slow-paced breathing among the healthy participants, but they employed longer periods of about 2 months.

However, concern has been raised about whether facemask application affects the effectiveness of deep breathing exercises and pulmonary functions. During the global pandemic, there was elevated demand for individual protective equipment, such as medical face masks, as recommended by the World Health Organization [11], which were viable in suppressing infectious virus transmission, alongside practicing social distancing. The present recommendation impacts most people in the world, including healthcare professionals, who are consistently required to wear face masks.

In particular, no study to date has examined the quantitative impact of the deep breathing exercise on pulmonary functions in the presence of a medical face mask. Such data may facilitate the assessment of relaxation exercises while wearing a medical face mask. Thus, this pre-and post-intervention within-subject design study was carried out to determine if wearing a medical face mask during deep breathing exercises affected respiratory performance and compare the results to deep breathing without wearing any face mask.

2. Methodology

2.1. Subject Selection

The subject of this study was one of the authors. No additional subject was recruited or involved in this study. The healthy 24-year-old male subject met the following inclusion criteria: (1) performing deep breathing for more than 5 min, (2) owning a telecommunication device for file storage, (3) being free from any medical condition, (4) not receiving or practicing deep breathing before, and (5) being a nonsmoker. Despite it being a single-subject study, it adhered to the Declaration of Helsinki from the World Medical Association, as this study involved human samples.

2.2. Study Design and Procedures

The impact of audio-guided deep breathing on the spirometry measurements was explored in two different settings: without a face mask and with a 4-ply medical face mask. The present research employed a pre- and post-intervention within-subject design study that involved the baseline measures, followed by audio-guided deep breathing without a face mask and spirometry measurement twice a day, in the morning and at night, for 25 days. For the next 25 days, the same spirometry measurements were taken before and after the audio-guided deep breathing, where the subject was required to wear a 4-ply medical face mask (Medicos, Ultra Soft Series) throughout the deep breathing process.

The experiment was conducted in a room with ambient lighting, a minimal level of noise, and adequate ventilation. Prior to the experiment, the subject was instructed to rest for 5 min to achieve physiological stability. The baseline spirometry measurements of the subject were acquired and recorded. Subsequently, the subject performed deep breathing, following the audio for 5 min using standard wired earphones, without wearing any face mask (Figure 1a).

Following the deep breathing session, the spirometry measurements of the subject were again measured. The same procedure was repeated for the next consecutive 25 days: once in the morning and once at night. The subject then continued the same procedure by wearing a standard 4-ply medical face mask for the remaining 25 days (Figure 1b). The audio-guided deep breathing was repeated with consistent support and guidance for each session throughout the 30-day period of study. The procedures are detailed in Table 1.

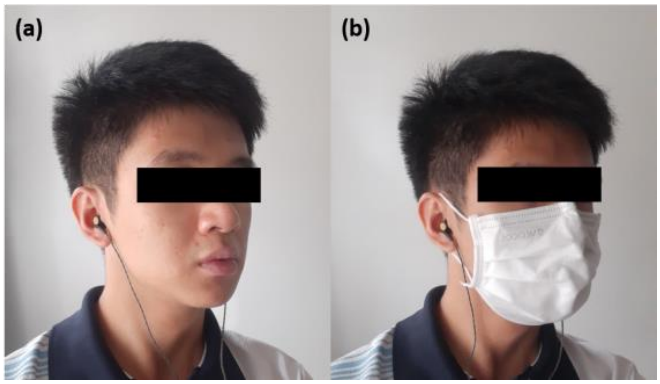


Figure 1. (**a**) Without a face mask and (**b**) with a standard 4-ply medical face mask (both with earphones).

Table 1. Measurement method used in this study.

	Baseline Measurement	Intervention	Follow-Up Measurement
Duration	Day 1 to day 25 (Without face mask) Day 26 to day 50 (With a standard 4-ply medical face mask)		
Outcomes [a]	TV, VC, FVC, FEV1, PEF, FEF25-75 (daily)		TV, VC, FVC, FEV1, PEF, FEF25-75 (daily)

[a]—TV—tidal volume; VC—vital capacity; FVC—forced vital capacity; FEV1—forced expiratory volume in 1 s; PEF—peak expiratory flow; FEF25-75—forced expiratory flow at 25–75% of forced vital capacity.

2.3. Development of Audio-Guided Deep Breathing

Figure 2 illustrates the audio-guided deep breathing method used in this study. Audacity®® Cross-Platform Sound Editor, version 2.4.2, was used to develop the audio clip. The audio clip was created at six breaths per minute with a total duration of 5 min. Cheng et al. [12] claimed that 5 min of deep breathing was the most optimal duration compared to the other durations proposed. Furthermore, the respiratory rate was proposed by Noble and Hochman [8], in which study it induced the coherent and resonance impacts of the neuro-mechanical interaction. The bird-chirping sound and the stream-flowing sound were developed and employed in this study. Each natural sound was adopted from royalty-free media clips [13,14] and selected according to the method in Ref. [15]. During the audio-guided deep breathing, the subject was required to inhale slowly and deeply in response to the bird-chirping sound and breathe out slowly and deeply in response to the stream-flowing sound while preserving the breathing rate. The subject needed to pay attention to his breathing and the flow through it while adhering to the natural sound guidance.

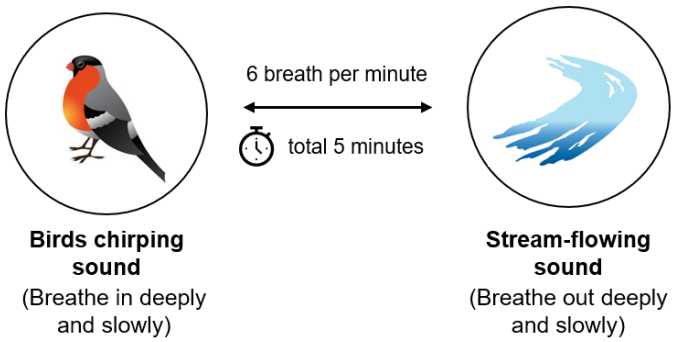


Figure 2. Audio-guided deep breathing.

2.4. Pulmonary Function Tests

The subject's spirometry was measured using two different autonomic digital spirometers: model SP80B (Contec Medical Systems Co., Ltd., Qinhuangdao, China) and model SY-8888 (Hangzhou Panhong Sports Goods Co., Ltd., Hangzhou, China), specifically designed for VC. For the measurement of TV, the subject exhaled in a one-way valve through a reusable mouthpiece attached to the spirometer during a single normal breath. To measure FVC and the forced expiratory volume in FEV1, PEF, and FEF25-75, the subject needed to exhale forcefully and speedily after a deep inhalation. Conversely, to measure VC, the subject exhaled in a similar setting but after a single deep inhalation. Following the reading displayed on the LCD screen, data from the three repeated measurements were used to obtain the best value. The attachable mouthpieces were removed and carefully sanitized according to the protocol before being reattached to the devices, maintaining appropriate hygiene before their subsequent usage.

2.5. Statistical Analysis

The data analysis was performed using IBM®® SPSS®® Statistics version 25. A normality test was conducted based on the statistical hypothesis to determine whether the data were normally distributed. The Shapiro–Wilk test was selected to identify the parametricity of the data, since this measure was used to appropriately analyze both small and large data samples at a significance level of $p < 0.05$. Using the mean difference of the spirometry before and after audio-guided deep breathing, a paired t-test was performed to test for the two-tailed test at a significance level of $p < 0.05$. As an alternative to the paired *t*-test, the Wilcoxon signed rank test was applied when the normality assumption of the data was disobeyed.

3. Discussions

We investigated whether deep breathing while wearing a face mask impacted the pulmonary functions associated with deep breathing with or without a face mask. The results are presented in Table 2. The results of this study revealed that all pulmonary parameters, including TV, VC, FVC, FEV1, PEF, and FEF25-75, significantly improved without a medical face mask. These findings were consistent with those of previous studies. A previous study demonstrated that 5 min of deep breathing with six breaths per minute significantly improved VC among healthy volunteers [16]. In this study, a healthy group using audio-guided deep breathing was tested for an identical breathing rate, and the results showed significant improvement in FVC, FEF25-75, TV, VC, and FEV1. During deep inspiration, the alveoli continued to expand beyond the regular stretch reflex, the intrapulmonary pressure was elevated, and the air occupied the alveoli sacs. The intrapulmonary pressure decreased and the alveoli sacs flattened at the beginning of the deep expiration [17]. Deep breathing improved ventilation via the strengthening of respiratory sinus arrhythmia when sympathetic activity decreased [18].

On the other hand, wearing a medical face mask impacted the respiratory function variables. One unanticipated result was a significant improvement in FEV1, whereas a significant reduction in VC was observed. Further, the results demonstrated that no significant changes were observed in TV, FVC, PEF, and FEF25-75 after audio-guided deep breathing, even though it marginally improved the functions. Previous studies showed that medical face masks imposed higher airway resistance on healthy populations in both resting and progressive exercising conditions [19,20]. There was also early evidence that lung function variables related to breathing resistance had similar impacts to that of upper airway obstruction caused by mouth resistance [21]. Since the average humidity and temperature of the exhaled air were approximately 31 °C to 35 °C and 66% to 76%, respectively [22], when carrying out deep breathing, the facial temperature, deformation, and humidity developed within the facemask increased breathing resistance [23]. Accordingly, the respiratory resistance altered the period required for breathing to achieve adequate ventilation, resulting in reduced ventilation function.

Table 2. Pair differences in respiratory function parameters before and after wearing a 4-ply medical face mask or no face mask.

Before–After	Paired Differences					*t*	*df*	Sig. (Two-Tailed) [b]
	M	SD	Standard Error	95% CI				
				Lower	Upper			
Without face mask								
TV (mL)	−38.04	46.965	6.709	−51.531	−24.551	−5.670	48	0.000 **
VC (mL)	−34.08	105.361	14.900	−64.023	−4.137	−2.287	49	0.027 *
FVC [a] (L)	−0.11	0.107	0.015	-	-	-	-	0.000 **
FEV1 (L)	−0.13	0.131	0.019	−0.170	−0.949	−7.120	49	0.000 **
PEF (L/s)	−0.36	0.736	0.106	−0.576	−0.149	−3.412	47	0.001 **
FEF25-75 (L/s)	−0.04	0.552	0.080	−0.593	−0.272	−5.422	47	0.000 **
With a 4-ply medical face mask								
TV (mL)	−2.96	34.187	4.835	−12.676	6.756	−0.612	49	0.543
VC (mL)	29.98	103.389	14.621	0.597	59.363	2.050	49	0.046 *
FVC (L)	−0.04	0.142	0.021	−0.081	0.002	−1.938	47	0.059
FEV1 (L)	−0.05	0.179	0.026	−0.104	0.000	−2.019	47	0.049 *
PEF (L/s)	−0.13	0.622	0.090	−0.312	0.049	−1.465	47	0.150
FEF25-75 (L/s)	−0.02	0.393	0.056	−0.133	0.092	−0.371	48	0.712

[a]—Wilcoxon signed-rank test; [b]—Significant value; * $p < 0.05$; ** $p < 0.005$.

However, these findings did not support the pulmonary implications of face masks during constant and maximum physical exercise. Fikenzer et al. [24] reported that pulmonary functions were significantly decreased in the healthy group in both rest and maximal exercise settings. Lässing et al. [19] also found that there was a significant reduction in pulmonary functions among healthy male subjects during continuous exercise. Combining all the pieces of evidence, it was found that the increment of the pulmonary functions with a medical face mask in this study was compromised by the deep breathing exercise. These findings had important implications for understanding the impacts of deep breathing exercises, despite the presence of a medical face mask.

The results need to be assessed in future studies using diverse samples or randomness to improve the external validity, since this study only involved a single male subject with repeated measures [25]. In addition, only medical facemasks were tested, and other types of facemasks, such as fabric and N95, still need to be tested. Different facemasks may lead to different psychological outcomes [26]. Despite such limitations, the findings of this study offered insights into the pulmonary impacts of deep breathing with and without facemasks.

4. Conclusions

Wearing a facemask during deep breathing appeared to impact respiratory performance with a decrease in TV, FVC, PEF, and FEF25-75. This implied that wearing a facemask was inadequate for physiological implications. In contrast, significant improvements were observed in all respiratory parameters of TV, VC, FVC, FEV1, PEF, and FEF25-75 in deep breathing without a facemask. Further investigations are needed with larger sample sizes and more diverse populations and the type of facemasks to generate more general implications.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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