BIOMECHANICS OF BREATHING WITH THE USE OF A FACE MASK AT REST

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The purpose of this study was to assess breathing patterns and the mechanics of individual breathing compartments (IBC) with and without a respirator (FFR) at rest. Twenty-one (11 M; 10 F) participants completed 10 min of breathing with or without FFR in a randomized order over two days. Three IBC were identified and measured through optoelectronic plethysmography: pulmonary rib cage, abdominal rib cage, and the abdomen. Simultaneously, data on inspiratory time, expiratory time, and respiratory frequency were gathered. The results indicated no significant differences in any of the parameters. This implies that the augmented respiratory effort due to the resistance of the FFR is uniformly distributed among the IBCs. Although there may be minimal immediate impacts of FFR on breathing patterns in healthy individuals during rest, long-term effects may vary.

KEYWORDS: filtering facepiece respirator, individual breathing compartments, respirator

INTRODUCTION: Respiration stands as a critical human function susceptible to the impact of a filtering facepiece respirator (FFR). During the Covid-19 pandemic, a large number of athletes were required to wear FFRs both during and in breaks between performances. Recent studies by Fikenzer et al. (2020) and Kyung et al. (2020), reported adverse effects of FFR on lung function including forced vital capacity. Earlier investigations propose that the detrimental effects of FFR on ventilation are contingent on the intensity of physical activity. During periods of rest or low exercise intensity, ventilation parameters generally remain stable (Roberge et al., 2010). However, there is a noticeable escalation in both inhalation and exhalation resistance (Roberge et al., 2010; Scheid et al., 2020). The introduction of resistance by the FFR, necessitating air passage through the mask, leads to a stronger inhalation and can result in increased respiratory muscle activity (Scheid et al., 2020). A rise in resistance during inhalation and exhalation, coupled with the introduction of additional dead space, may alter the biochemical cues influencing breathing, ultimately impacting breathing patterns and ribcage mechanics. Consequently, we hypothesize an elevated demand on certain respiratory muscles to sustain optimal respiration. Altered activation of respiratory muscles could potentially result in unfavourable modifications to breathing patterns (i.e., increased upper thoracic compartment contribution) or posture. Hence, the objective of this study is to evaluate the influence of FFR on breathing patterns and respiratory compartments during rest, utilizing Optoelectronic Plethysmography (OEP).

METHODS: Twenty-one (11M; 10 F) healthy, highly active students of physical education and sport participated in this study. Participants made two visits to the laboratory, completing one test during each session: Optoelectronic Plethysmography (OEP) assessment while standing at rest. The time gap between testing days was set at 72 hours. Participants were randomly divided into two groups: one group underwent test wearing Filtering Facepiece Respirators (FFR), while the second group underwent testing without the mask. During the second visit, participants switched conditions. The N95 respirator (Promedor24, Czech Republic) was selected as the standard for protecting against aerosol transmission during the COVID-19 pandemic (Au, 2021). During the standing test, participants maintained a stationary position, engaging in spontaneous, quiet breathing without speaking or altering their posture throughout the OEP data collection. The first two minutes served as an adaptation period, followed by the collection of data for an additional ten minutes. The study was approved by the Ethics

Committee of Faculty of Education, University of South Bohemia, Ref. No.: 031/2023, from 30th December 2023.
An analysis of the breathing pattern and chest wall compartment volumes was performed using opto-electronic plethysmography (BTS Bioengineering, Milan, Italy). The system comprises eight cameras, with five positioned anterior and three posterior to the participant. Additionally, 89 reflective markers were strategically placed on the subject's chest, abdomen, and back to facilitate mapping of the trunk (Figure 1) (Fermi & Aliverti). Previous studies have demonstrated the reliability of this technique both at rest and during maximal exercise (Aliverti et al., 2005). The contributions of each breathing compartment (V_{RCp}- pulmonary rib cage, V_{RCa}- abdominal rib cage, V_{Ab}- abdomen) were determined using the difference between end-inspiratory and end-expiratory volume. The exact method of calculating chest wall kinematics with OEP has been described in prior work (Aliverti & Pedotti, 2002).

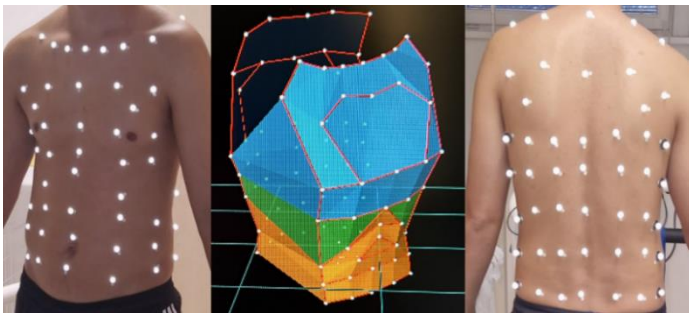

Figure 1: The marker set up with 3D model.

The data were presented with mean values and standard deviations. Prior to conducting any statistical analyses, the normality and homogeneity of the data were verified through histogram analyses and Shapiro-Wilks tests. A One-way ANOVA was employed for comparing breathing compartment parameters between sessions. Additionally, a t-test was used to compare parameters related to breathing patterns (T_I, T_E, fR). The significance level was set at $\alpha = 0.05$, and data processing was carried out using Excel 2016 (Oregon, WA, USA) and SPSS version 25.0 (IBM Corp., Armonk, NY, USA). The practical significance of observed differences was assessed using Cohen's d effect size statistics, with the magnitude scale categorized as follows: small (0.2–0.5), moderate (0.5–0.8), and large effect (>0.8).

RESULTS: The pulmonary function parameters and IBC contributions are presented in Table 1 and Figure 2. During the standing position no significant differences between conditions were observed in fR, T_I, or T_E.

Table 1: Breathing pattern parameters and individual contribution of each breathing sector at rest.

Measure	Masked	Unmasked	MD (95% CI)	*p* value	*d* value
fR	13.8 ± 3.4	13.7 ± 4.1	0.14 (-1.54, 1.25)	0.83	0.03
T_I [s]	2.02 ± 0.61	2.13 ± 0.94	-0.11 (-0.23, 0.44)	0.51	0.13
T_E [s]	2.61 ± 0.76	2.83 ± 1.18	-0.22 (-0.13, 0.57)	0.21	0.21
V_{RCp} (%V_T)	44.1 ± 9.0	43.4 ± 8.9	0.68 (-4.20, 2.83)	0.69	0.07
V_{RCa} (%V_T)	17.1 ± 3.7	17.7 ± 4.5	-0.60 (-1.55, 2.76)	0.57	0.14
V_{Ab} (%V_T)	38.7 ± 9.6	38.8 ± 9.1	-0.08 (-3.39, 3.55)	0.96	0.01

Notes. MD – mean difference; CI – confidence interval; fR – respiratory frequency; T_I – Inspiratory time; T_E – Expiratory time; V_{RCp} – Pulmonary rib cage ; V_{RCa} – Abdominal rib cage; V_{Ab} – Abdomen;
The contributions of IBCs are presented in Figure 2. There were no significant differences between conditions in any measured compartment.

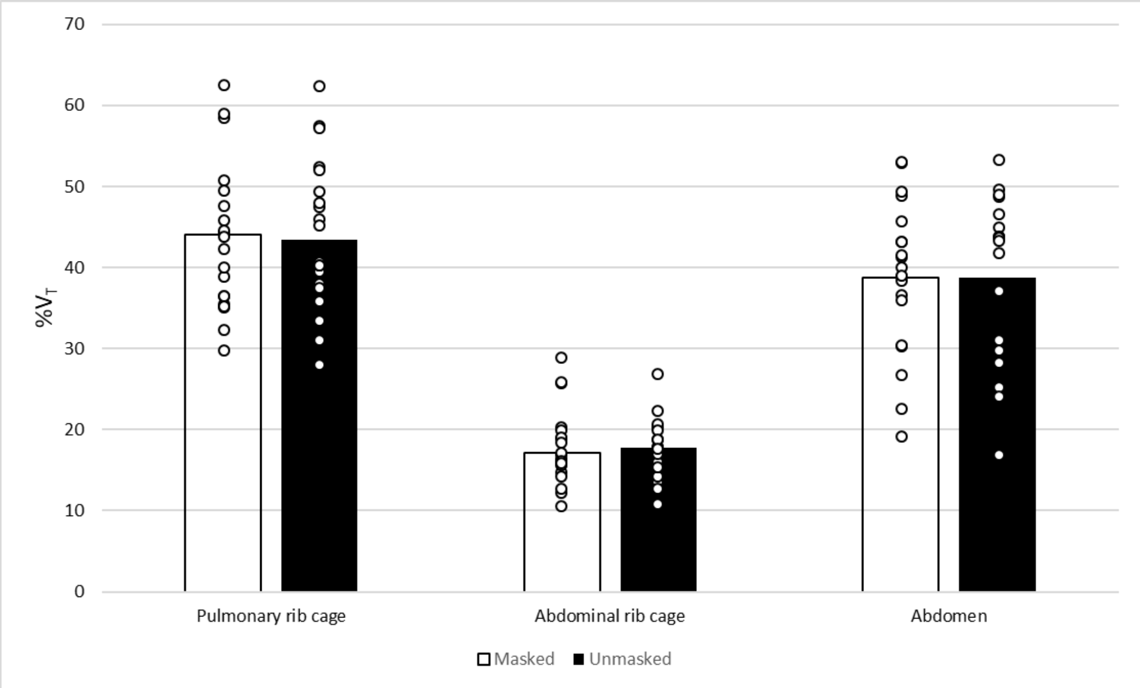

Figure 2: The contribution of IBCs during rest.

DISCUSSION: The primary objective of this investigation was to explore alterations in breathing pattern induced by the use of FFR. Despite an increase in breathing resistance, there were no significant differences observed in the contribution of individual breathing compartments and pulmonary function parameters between FFR-wearing conditions during rest. These results align with prior research, indicating no statistically significant differences in respiratory frequency among 22 female subjects with and without the use of FFR for 20 minutes. In contrast, the study of Mapelli et al. (2021) found 22.7 % decrease in respiratory frequency with the use of FFR. The discrepancy in results might be attributed to the utilization of a spirometry mask over the FFR in the Mapelli et al. (2021) research.

Prior research demonstrated an elevation in respiratory muscle activity when individuals wore FFR, as highlighted by Scheid et al. (2020). This heightened activity is attributed to the increased resistance encountered as air passes through the mask. The overuse of specific accessory respiratory muscles can result in alterations to posture (Corrêa & Bérzin, 2008).

This finding is meaningful since there is a growing prevalence of upper-thoracic dominant breathing within the general population (Gilbert et al., 2014). Upper-thoracic dominant breathing is typically viewed as dysfunctional, as it can lead to chronic overloading of respiratory muscles in the subclavian sector and unfavourable structural changes (Gilbert et al., 2014).

OEP provides an indirect means of assessing the work of ventilatory muscles by analyzing the motion patterns of distinct breathing compartments. This approach serves as a viable proxy for investigating respiratory muscle activity in conjunction with FFR, eliminating potential contamination associated with spirometry masks (Kim et al., 2018). To the best of our knowledge, no prior study has evaluated the impact of FFR on the contribution of IBCs.

In the current investigation, the involvement of IBC did not exhibit significant differences between conditions during rest. Computational modeling estimates that the use of an N95 mask leads to an exponential increase in work of breathing and about 11.53% at rest (Monjezi & Jamaati, 2021). Our findings indicate that the augmented work of breathing induced by the respirator is uniformly distributed among individual breathing compartments. This contrasts with investigations involving inspiratory muscle training (IMT) and IBC musculature. The study conducted by Hellyer et al. (2015) explored the acute effects of IMT at 40% of maximal inspiratory pressure on respiratory muscle electromyography (EMG) activity at rest. Results revealed increased activity in the sternocleidomastoid muscle with IMT during rest.

The present findings showed a 2.9% increase in pulmonary rib cage volume (95% CI: -7.6 to 3.8), consistent with the study by Hellyer et al. (2015); however, this difference was neither statistically nor clinically significant (1.2% below the SWC).
It is crucial to acknowledge the limitations of this study. The participants comprised young, healthy, and physically active students majoring in physical education and sports. Moreover, it's noteworthy that neither the study team nor the participants were blinded to the conditions involving masked or unmasked states.
CONCLUSION: Previous studies have outlined the impact of FFR on pulmonary parameters. This study was specifically crafted to investigate how FFR influences the contribution of individual breathing compartments. Despite the heightened workload on respiratory muscles, it appears that the contribution of individual breathing compartments remains consistent when utilizing FFR at rest.
It's essential to approach the interpretation and generalization of these results with caution, given that the study focused on the acute effects of FFR rather than long-term impacts. Additionally, the participants involved in this study were well-trained, physically active males and females. Therefore, caution should be exercised when extending these findings to individuals with chronic pulmonary or cardiac conditions or those who smoke, as they may exhibit different physiological responses.

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