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Original Article

A Long-term effects of wearing a reusable mask while running exercises on blood gas levels in adults

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Abstract
Introduction: There is growing concern around the world regarding pandemic diseases of the respiratory system, including Coronavirus disease 2019 and tuberculosis, and the health problems associated with air pollution, which have led to wearing of protective masks in daily life, including during running exercises. **Purpose:** To study and compare the long-term effects of wearing reusable masks while running exercises on blood gas parameters and on haematocrit levels in adults. **Methods:** Fifteen healthy volunteers, aged 25–40 years old, were randomly assigned to two groups: moderate- and vigorous-intensity running groups. Both groups wore reusable masks that could filter air at 95% during running exercises for a period of 6 weeks. **Results:** Carbon dioxide in arterial blood and bicarbonate levels in red blood increased significantly ($p<0.05$) after wearing reusable masks during running. A comparison between the two groups revealed that the bicarbonate levels in arterial blood in the vigorous exercise group were significantly higher than those in the moderate exercise group ($p<0.01$), but there were no significant differences between the groups in the other variables tested. **Conclusions:** Wearing a mask while running for a prolonged time was associated with primary respiratory acidosis. However, the body retained the ability to reduce the blood pH without increasing the number of blood cells. Instead, rectification was performed through the proximal ureter, using bicarbonate as the chemical substrate. Consequently, a decrease in the amount of water in the blood was observed, which was associated with marked viscosity of the blood.
Key Words: Mask, Running, Exercise, Haematocrit, Arterial blood Gas.

Introduction

The world has been facing a global emergency since the onset of the Coronavirus disease 2019 (COVID-19) pandemic. More than 500 million people have been infected worldwide and more than 6 million individuals have died (World Health Organization, 2022). In addition, tuberculosis, a respiratory infection that continues to be a major public health problem in the world and has not yet been eradicated. By 2020, more than 1.3 million people will have died from tuberculosis annually (World Health Organization, 2021). Both diseases are transmitted through the air via airborne transmission, and air pollution containing particulate matter (PM) 2.5 can result in acute health in both an acute phase, such as allergies and inflammatory diseases of the respiratory tract or acute heart failure, as well as have an impact on long-term health, including cardiovascular disease and cancer (World Health Organization Thailand, 2019). Thus, the spread of infectious diseases is facilitated through airborne transmission (Liu et al., 2018). Learning to wear masks in everyday life (Chu et al., 2020; Hendrix, 2020), and wearing a mask during running activities, especially in a gym or in a confined space to prevent respiratory diseases should be a priority (Atrubin, Wiese, & Bohinc, 2020; Chu et al., 2020; Douglas, Katikireddi, Taulbut, McKee, & McCartney, 2020; Jang, Han, & Rhee, 2020).A study performing aerodynamic simulations in a wind tunnel found that when speaking normally while standing was associated with a diffusion of airborne secretions of a radius of 1.5 to 2 m, but on moving, especially during active exercises such as walking, running, or cycling with higher breathing rates, droplets of secretions can spread backwards from 6 m to 20 m (Blocken, Malizia, van Druenen, & Marchal, 2020; Jones et al., 2020). The most popular exercise activity is running, which is popular in the adult population aged 25–59 years old and involves more than 6.8 million people, or approximately 10% of the total population in Thailand (DEPARTMENT OF PHYSICAL EDUCATION, 2020). Given the concerns regarding the transmission of airborne pathogens, individuals have begun wearing a mask while running (Chandrasekaran & Fernandes, 2020).

The respiratory system plays an important role during running exercises and is highly impacted by wearing a face mask. The respiratory system involves the intake of air into the lungs in exchange for oxygen gas (O_2), which the body can use as a source of energy and convert to carbon dioxide (CO_2), a waste product of energy generation that is then excreted by the body. When inhaled, air travels down to the lungs and the gas exchange occurs through diffusion. Subsequently, chemical processes in blood vessels will transport both O_2 and CO_2 to body cells (Panawala, 2018). However, wearing a hygienic mask while running results in the body

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receiving less O_2 and results in CO_2 respiration, which is also known as rebreathing CO_2 (Chesta et al., 2021) and the retention of CO_2 in the blood has an impact on the acid and base (pH) equilibrium of the blood. To be able to analyse these effects effectively, it is necessary to measure the changes in arterial blood gas (ABG) levels, which is not commonly performed in veins and capillaries because it leads to a greater errors than arterial blood analysis. In particular, the values of carbon dioxide (pCO_2) and blood oxygen (pO_2) are so different that they can not be used to compare clinical outcomes (Bloom, Grundlingh, Bestwick, & Harris, 2014; Byrne et al., 2014). When wearing a mask, performing moderate and vigorous intensity exercises will require a different maximum heart rate (HRmax) at different intensity levels.

The body requires additional energy expenditure that increases the need for O_2 gas and stimulates further the removal of CO_2 from the body. However, wearing a mask favours the re-breathing of CO_2, which the body then accelerates to remove and thus, causes the body to use a corrective process or compensation by stimulating shortness of breath and increasing the haematocrit (HCT) to help bind more O_2 gas. Vigorous intensity levels are more likely to result in changes in ABG and HCT levels than moderate-intensity levels. Currently, there are studies on the acute effects of wearing masks during jogging in moderate and vigorous intensity exercises, which indicated that there were no statistically significant differences in blood gas and HCT levels during exercise in masked and non-masked participants (Barbieri et al., 2020; Bourassa, Bouchard, & Lellouche, 2018; Fikenzer et al., 2020; Kim, Benson, & Roberge, 2013; Lauren et al., 2015; Sellers, Monaghan, Schnaiter, Jacobson, & Pope, 2016; Shaw, Butcher, Ko, Zello, & Chilibeck, 2020). However, acute effect of exercising have not yet be evaluated to determine whether moderate intensity and vigorous intensity exercise may affect blood gas and HCT values; therefore, long-term studies are needed. The objective of this study was to compare the long-term effects of wearing reusable masks during running exercises on blood gas (PaO_2, $PaCO_2$, pH, and HCO_3) and HCT levels in adults.

Materials and methods

Participants

The volunteers in this study were adults (males and females), aged 25–40 years old, healthy, with no underlying disease. Participants did not drink alcohol, did not smoke, and exercised regularly for at least 6 months. Females were not pregnant and passed the assessment of readiness to engage in physical activity score (PAR-Q+2019). Twenty-five volunteers (11 males and 14 females) were enrolled from 5400 social network of runners in the Chatuchak Park, UA Run Crew (Thailand), and jogging in Chatuchak Park Groups from Bangkok, Thailand participated in the study. The sample size was calculated using the program G*power Version 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009).

Study outcomes

Independent variables included two intensity running exercises types: moderate-intensity (64%–76% of maximum heart rate) and vigorous intensity (77%–95% of maximum heart rate). The dependent variables included the evaluation of the following ABG parameters: blood oxygen concentration: PaO_2, blood carbon dioxide concentration: $PaCO_2$, pH level, bicarbonate: HCO_3, and haematocrit levels: HCT.

Intervention

Volunteers were randomly assigned to two groups: a moderate intensity (64%–76% HRmax) group and a vigorous intensity (77%–95% HRmax) group. Intensity referred to the level of exercise intensity according to the 10th edition ACSM Guidelines for Exercise Testing and Prescription (American College of Sport Medicine, 2018). Both groups wore N95 standard reusable masks 5 days a week for 6 weeks. Heart rate was monitored using a heart rate wristband. The study was designed to use a home exercise method, and volunteers sent pictures showing them wearing masks, their exercise results, and heart rate images from using the Huawei Health application (Version 10.1.1.312) to the researcher after each exercise. The researcher recorded the data obtained from the volunteers using a computer.

Outcome measures

The maximum oxygen consumption (VO_2max) and maximum heart rate were measured using a gas analyser, CARDIOCOACH (USA), and treadmill brand Circle Fitness (USA), 24–48 h prior (before) and 24–48 h after participation in the programme. Arterial blood samples (1.5 mL of arterial blood was collected from the radial artery at the wrist area) were analysed immediately using a Blood Gas Analyzer Brand Radiometer (ABL Flex 80 Basic (Denmark) twice. The first measurement was taken after the first VO_2max measurement and the second was performed after the second VO_2max measurement at the Department of Sports Science, Faculty of Physical Education, Srinakharinwirot University, Bangkok, Thailand. All volunteers wore a reusable N95 mask certified by the Bureau Veritas Certification, 2021 (GQmax MASK, Supara Co., Ltd, Bangkok, Thailand) during all exercises.

Ethical requirements

This study was approved by the Human Research Ethics Committee, Srinakharinwirot University, Bangkok, Thailand (research registration number SWUEC/E/G-116/2564) and the Thailand Clinical Trials Registry (TCTR) (research registration number TCTR20220816001). This research was conducted in compliance with international ethics principles, regulations, requirements, domestic and international law, and with the Declaration of Helsinki. This study was funded by the National Research Council of Thailand (NRCT).

Statistical Analysis

To examine differences in the data sets, comparison of means of the two independent samples (t-test) were used to check the equality of the data. The data were reported as the mean, standard deviation (SD) and a symmetrical distribution using the skewness statistic was evaluated based on the rule of thumb, with values in the range of +1.96, Data were statistically analysed using two-way MANOVA and multiple analysis of variance using Pillai's Trace statistic to study the interaction between intensity levels and time periods of wearing reusable face masks on ABG levels (PaO_2, $PaCO_2$, pH, and HCO_3) and HCT. Dependent variables were analysed separately using Hotelling's T^2. A Pillai's Trace statistic was used to perform a single-variable analysis (univariate) if statistically significant differences were found. We set a statistically significant difference at the level of $p<0.05$, with a IBM SPSS Statistics version 26.0.0.0 32 Bit Edition programme (IBM Corporation, 2019).

Results

Study population

Twenty-eight participants were selected for this study; three (10.71%) declined to participate in the study, three (10.71%) were unable to provide blood samples and seven (25.00%) did not meet the inclusion criteria. Fifteen participants (53.58%) completed the study. Three of the 15 subjects (20%) were unable to provide the required data and thus, satisfied the exclusion criteria. Overall, data from 12 subjects (80%) were used for the statistical analysis. From the calculation of the sample size, it was found that a sample of 12 individuals was sufficient for the statistical analysis (Fig.1).

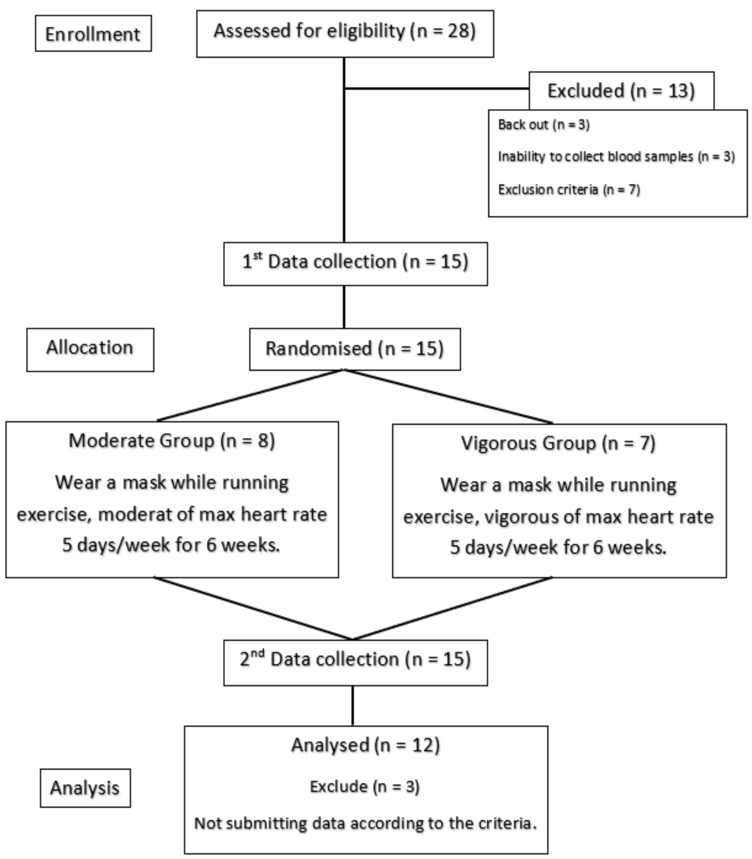

Fig.1. Flow diagram of participants in the trial

The twelve volunteers, 10 males, and 2 females were randomized into two groups. The general data of the volunteers were measured 2 time at before and after conducting the intervention to examine the differences in the data sets. Therefore, the researcher used a statistical analysis by comparing the mean between the two independent samples (t-test) to check the equality of the data.

The analysis, mean, standard deviation (± SD), symmetrical distribution using Skewness statistic based on the rule of thumb, with values in the range of + 1.96. There was no statistically significant difference found between group (intensities) in the period before wearing the mask and after wearing the mask (Table 1, 2).

Table 1. Characteristics of the participants prior to the intervention.

Characteristics of the Participants	Pre						
	Moderate Group		Vigorous Group		Skewness	t	Sig.
	Mean	± SD	Mean	± SD			
Sex (No.)	Male = 5	Female = 1	Male = 5	Female = 1	1.327	- 0.620	0.549
Age (Year)	35.00	± 2.76	32.33	± 4.80	- 0.657	1.180	0.265
Weight (Kg.)	71.48	± 10.88	65.08	± 14.37	0.27	0.870	0.405
Hight (Cm.)	166.33	± 9.52	171.50	± 7.23	- 1.404	- 1.058	0.315
Time of use mask in a day (Hour)	7.33	± 2.16	8.50	± 2.35	- 0.638	- 0.896	0.391
SpO2 (%)	99.83	± 0.41	99.00	± 1.10	- 1.945	1.746	0.111
VO2max (Ml./Kg./min.)	44.37	± 10.69	46.85	± 9.98	- 0.617	- 0.416	0.686
HRmax (Beats/min.)	177.67	± 6.44	179.50	± 8.37	- 0.871	- 0.426	0.679

Skewness statistics were based on the rule of thumb, with values in the range of +1.96. Significance was set at a P <0.05.

Table 2. Characteristics of the participants after the intervention.

Characteristics of the Participants	Post						
	Moderate Group		Vigorous Group		Skewness	t	Sig.
	Mean	± SD	Mean	± SD			
Sex (No.)	Male = 5	Female = 1	Male = 5	Female = 1	1.327	- 0.620	0.549
Age (Year)	35.00	± 2.76	32.33	± 4.80	- 0.657	1.180	0.265
Weight (Kg.)	71.48	± 10.89	65.08	± 14.37	0.270	0.870	0.405
Hight (Cm.)	166.33	± 9.52	171.50	± 7.23	- 1.404	- 1.058	0.315
Time of use mask in a day (Hour)	7.33	± 2.16	8.50	± 2.35	- 0.638	- 0.896	0.391
SpO2 (%)	99.00	± 0.63	99.00	± 1.26	- 0.755	0.000	1.000
VO2max (Ml./Kg./min.)	46.25	± 9.85	49.53	± 15.53	0.767	- 0.437	0.671
HRmax (Beats/min.)	177.33	± 8.33	180.33	± 7.50	0.490	- 0.655	0.527

Skewness statistics were based on the rule of thumb, with values in the range of +1.96. Significance was set at a P <0.05.

Adverse Events

During arterial blood sample collection, one female volunteer experienced anxiety leading to nausea, dizziness, and vomiting, which was considered generalised anxiety. During the second arterial blood sampling, one male volunteer experienced anxiety that led to spasticity, tremors, shortness of breath, and coldness in the hands and feet, which were considered symptoms of generalised anxiety. Both volunteers received first-aid treatment until they returned to normal. The doctor examined both volunteers and determined that they could continue to participate in the study.

Table 3. The mean and standard deviation (+SD) values at before and after of the moderate and the vigorous intensity groups.

Dependent Variable	Pre				Post				Change (%)	
	Moderate Group		Vigorous Group		Moderate Group		Vigorous Group		Moderate	Vigorous
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD		
	7.39	±	7.41	± 0.13	7.37	± 0.34	7.39	± 0.32	- 00.02	- 00.02
pH	102.83	0.44	99.17	±	79.17	±	85.83	±	(- 00.27)	(- 0.27)
PaO_2 (mm	37.28	±	39.27	29.10	41.95	27.78	44.52	34.46	- 23.66	- 13.34
Hg)	22.00	6.31	24.18	± 3.56	23.72	± 4.80	26.15	± 7.21	(- 23.01)	(- 13.45)
$PaCO_2$ (mm	45.83	±	46.67	± 1.74	43.00	± 1.28	44.67	± 2.61	04.67	05.25
Hg)		6.14		± 4.97		± 5.44		± 3.83	(12.53)	(13.37)
HCO_3 (mm		±							01.72	01.97
Hg)		2.06							(07.82)	(8.15)
HCT (mEq/L)		±							- 02.83	- 02.00
		3.31							(- 06.17)	(- 4.29)

Six volunteers from the moderate running group and six volunteers from the vigorous running group were included in the analysis. The mean values and standard deviations (+SD) for both groups are presented in Table 3. The two-way MANOVA using Pillai's trace statistic found that there were no interaction effects from the training periods or from the intensity of running for any of the dependent variables, pH (F=0.035, df=1, MS=3.75, p=0.853), PaO_2 (F=0.225, df=1, MS=160.17, p=0.105), $PaCO_2$ (F=0.016, df=1, MS=0.510, p=0.90), HCO_3 (F=0.024, df=1, MS=0.094, p=0.879), and HCT (F=0.052, df=1, MS=1.042, p=0.822). Furthermore, Pillai's trace statistic found that differences in the values of PaO_2, $PaCO_2$, pH, and HCT between the groups (effects of exercise intensity) were not significantly different (all, p>0.05); however, the values of HCO_3 were significantly different (F=8.136, df=1, MS=31.970, p=0.010, Eta=0.289) (Fig.2). The pH, PaO_2 and HCT values in arterial blood before and after masking were not significantly different (all, p>0.05); however, differences in the values of $PaCO_2$ and HCO_3 values before and after masking differed significantly (F=4.706, df=1, MS=147.510, p=0.042, Eta=0.190), and (F=5.179, df=1, MS=20.350, p=0.034, Eta=0.206, respectively) (Fig.3). $PaCO_2$ levels increased in the moderate- and vigorous-intensity groups by 12.53% and 13.37%, respectively. HCO_3 levels increased by 7.82% and 8.15% in the moderate and vigorous intensity groups, respectively (Table 3).

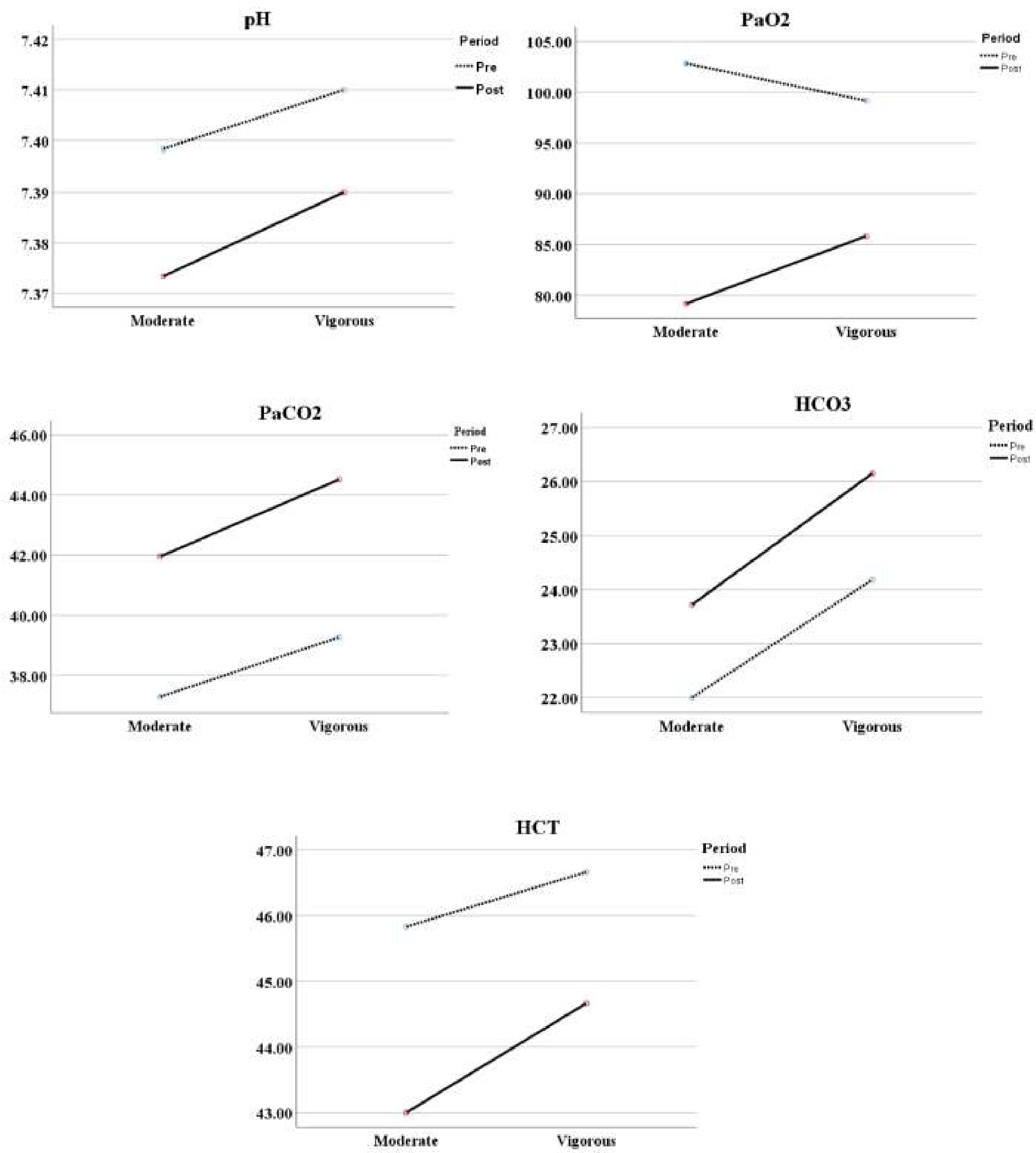

Fig.2**.** PaO_2, $PaCO_2$, pH, and HCT values between groups were not different (all, p>0.05); but, HCO_3 values were significantly different.

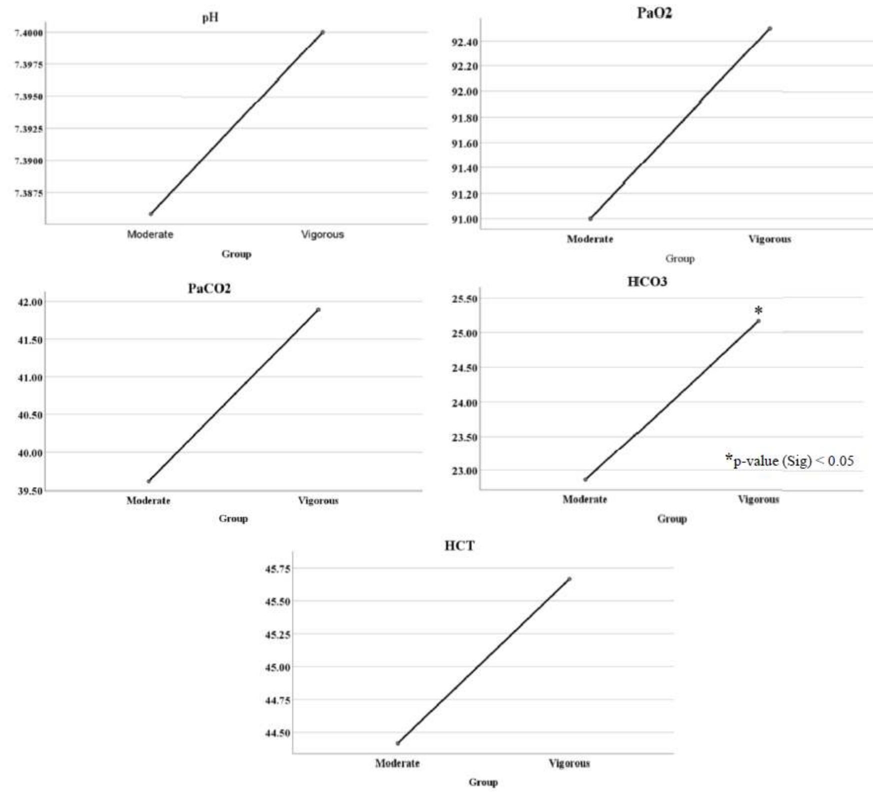

Fig.3. pH, PaO_2, and HCT values in the arterial blood before and after wearing the mask were not different (all, $p>0.05$); with the exception of $PaCO_2$ and HCO_3 ($p<0.05$).

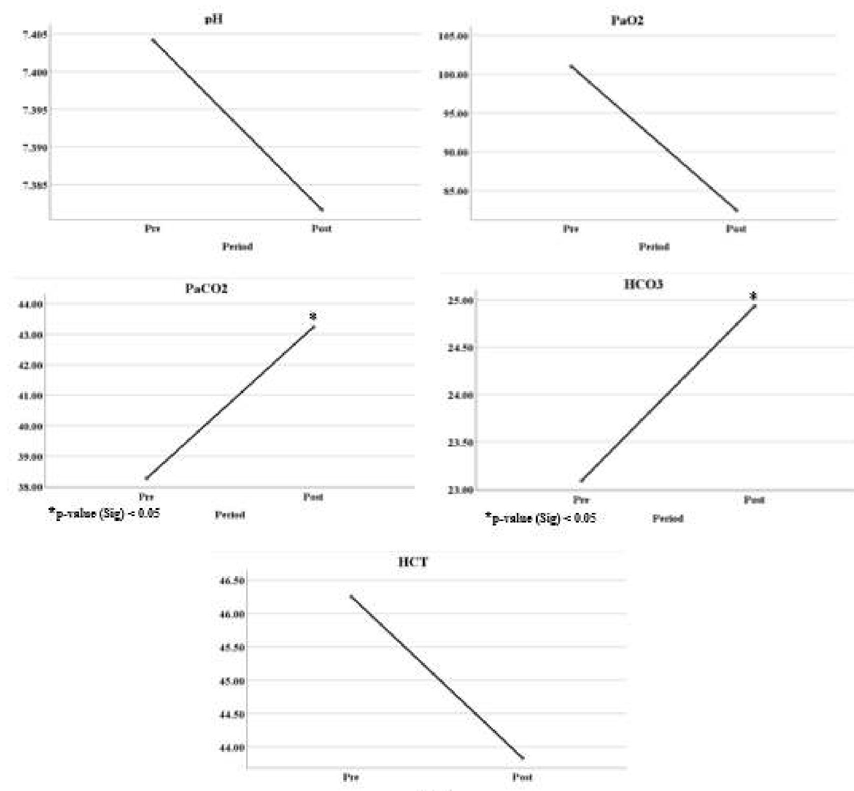

Figure 4. pH, PaO_2, and HCT values in arterial blood between before and after wearing the mask were not significant different (all, $p > .05$); but, $PaCO_2$ and HCO_3 were significant different.

Discussion

The results of a six-week mask wearing period during running exercises found there were no changes in pH, PaO_2 and HCT levels; with the exception of changes in $PaCO_2$ and HCO_3. Running exercise at vigorous intensity resulted in higher HCO_3 levels than exercise at moderate intensity. This was due to the re-inhalation of CO_2, a waste product produced by the metabolic respiration process used to synthesize adenosine triphosphate (ATP). During the metabolic respiration process, CO_2 diffuses from cells into veins and spreads through the capillaries surrounding the alveoli into both lungs and is expelled by exhalation. However, wearing a mask acts as a barrier that prevents effective elimination of CO_2. As a result, CO_2 is inhaled into the lungs once again (rebreathing CO_2) and results in an increase in the levels of PCO_2. When shifts in these levels are detected by the body, the brain, medulla oblongata, and pons respond by increasing the respiration rate to accelerate the removal of CO_2 through the respiratory system. This is the body's first defence mechanism; however, this response occurs repeatedly and the amount of CO_2 does not decrease, the body proceeds towards a secondary mechanism involving a gas exchange system or chemical regulatory response. The increase in CO_2 from inhalation (rebreathing CO_2) reduces the amount of oxyhaemoglobin (HbO_2) because CO_2 in the breath will diffuse back into the capillaries surrounding the alveoli, causing it to bind to haemoglobin (Hb), thus increasing carbaminohaemoglobin ($HbCO_2$) levels (Chandrasekaran & Fernandes, 2020). As CO_2 can bind to haemoglobin 200–300 times more strongly than O_2, there is an increase in the amount of $HbCO_2$ in the bloodstream. The amount of CO_2 in the arterial blood ($PaCO_2$) and bicarbonate (HCO_3) in the arterial blood also increased.

The vigorous exercise group exhibited a higher increase in HCO_3 levels than the moderate exercise group. Different running intensity levels resulted in additional energy consumption. During the same period, the vigorous exercise group had a higher demand for O_2 than the medium exercise group, which used O_2 in the ATP synthesis process and resulted in an increased elimination of CO_2. Initially, the mechanism was the same as in the moderate intensity group; however, the increase in running intensity caused an increase in the compensation system. When the pCO_2 in the blood increases, the ability of Hb to bind O_2 from pO_2 is reduced, resulting in the formation of $HbCO_2$, which in turn, produces higher HCO_3 levels in the arterial blood in the vigorous exercise group than in the moderate group. Considering the results of this study and the effects of wearing reusable masks during running exercises at moderate and vigorous intensity, respiratory acidosis is associated with respiratory acidosis. When the body switches to the renal compensation process, the kidneys reabsorb water (H_2O), store HCO_3, and expel hydrogen ions (H^+) from the body. This increases the viscosity of the blood because water in the blood is lost during this process. CO_2 emissions (consistent with the postmask wearing blood testing of all volunteers) were attributed to primary respiratory acidosis (Patel S & Sharma S, 2022). Arterial blood ($PaCO_2$) and HCO_3 were significantly higher in the post-test measurements in both groups than at the pre-test assessment. To maintain the acid and base pH balance in the blood, a corrective compensation mechanism was induced by the kidneys, but with no significant changes in the HCT (Zouboules et al., 2018). However, the volume of blood decreased, resulting in greater viscosity in the post-masked blood testing values of all subjects than in the pre-masked values, and ultimately correlated with the onset of relative polycythaemia. The results of the study indicate that primary respiratory acidosis results from high intensity running exercises in individuals wearing a mask, and when combined with polycythaemia, there is potential for the development of a high blood clotting status.

Conclusions

The study results revealed that there were no variables with a precise change. The increase in arterial blood HCO_3 resulted from an increase in hydrogen ions (H^+), a waste product of intracellular synthesis and respiration of ATP. CO_2, which the body accelerates to eliminate before rebreathing (Chesta et al., 2021), is corrected by the body using a renal compensatory mechanism, and thus, acidosis is avoided or a blood pH >7.35 is ensured. This chemical transformation process involves the adjustment of the bicarbonate buffer system, which binds HCO_3 with hydrogen ions (H^+) to form carbonic acid (H_2CO_3), which in turn dissociates into CO_2 and H_2O. This rectification process coincides with increases in respiration and heart rate. Renal compensation uses the process of bicarbonate reabsorption (bicarbonate reabsorption) in the proximal tubule, where HCO_3 binds to hydrogen ions (H^+) to become acidic. Carbonic acid (H_2CO_3), in the brush-border epilthelial cells, converts H_2CO_3 to H_2O and CO_2 gas, which are finally reabsorbed through the kidneys. Additionally, fluid loss occurs during this process in the form of HCO_3.

This study showed that wearing a reusable masks during running exercise at moderate and vigorous intensities is associated with respiratory acidosis (Patel S & Sharma S, 2022). The body uses a mechanism of renal compensation, whereby the kidneys reabsorb H_2O, store HCO_3, and expel hydrogen ions (H^+) from the body. This increases blood viscosity because H_2O in the blood is eliminated during this process (Zouboules et al., 2018). CO_2 emissions, as evaluated in the post-mask blood testing of all volunteers, led to the development of primary respiratory acidosis. The effects of wearing a reusable mask while exercising at moderate and vigorous intensity have adverse health effects. The body uses a compensatory process to maintain the pH balance in the blood and accelerates the elimination of CO_2 from the body. In particular, the high-intensity running exercise reduced fluid levels in the blood, which was in turn associated with blood thickening or relative polycythaemia. Further study is required to obtain clear conclusions about the mechanisms subsequent to wearing a reusable mask while running, including the body's adaptive responses. According to the study results, moderate-intensity running exercises while wearing a mask can be recommended, if needed.

Study limitations

This study was limited in data collection due to the restrictions of the COVID-19 pandemic. In Bangkok, an area facing strict lockdown measures in response to declaration of a state of emergency by the Thailand government administration, the study needed to be adjusted to allow volunteers to take greater responsibility in terms of ensuring the performance of home-based running exercises, and the inability to control variables by experimenters. Data were obtained based on the responsibility of individual volunteers. The investigators were unable to increase the number of subjects to the specified threshold due to budget constraints and the age limitations of the participants. Given the volunteers' concerns about the COVID-19 pandemic, most study subjects were concerned about participating in this research project. Furture studies should enrol a greater number of volunteers, which will provide a greater opportunity to clearly demonstrate a relationship between the variables.

Conflicts of interest

The study was funded by the National Research Council of Thailand (NRCT) under Grant No. (2564NRCT322233)

Reference

American College of Sport Medicine, 2018, *Guidelines for Exercise Testing and Prescription*. Wolters Kluwer, China

Atrubin, D., Wiese, M., & Bohinc, B. (2020). An outbreak of COVID-19 associated with a recreational hockey game—Florida, June 2020. *MMWR Morb Mortal Wkly,* **69**(41), 1492.

Barbieri, J. F., Gáspari, A. F., Teodoro, C. L., Motta, L., Castaño, L. A. A., Bertuzzi, R., ... de Moraes, A. C. (2020). The effect of an airflow restriction mask (ARM) on metabolic, ventilatory, and electromyographic responses to continuous cycling exercise. *Plos One,* **15**(8), e0237010.

Blocken, B., Malizia, F., van Druenen, T., & Marchal, T. (2020). Towards aerodynamically equivalent COVID19 1.5 m social distancing for walking and running. Questions and Answers. Website Bert Blocken, Eindhoven University of Technology *(*The Netherlands*)* and KU Leuven (Belgium). Available at*:* http*://*www.urbanphysics.net*/*COVID19.html (Last accessed 21 April 2020).

Bloom, B. M., Grundlingh, J., Bestwick, J. P., & Harris, T. (2014). The role of venous blood gas in the Emergency Department: a systematic review and meta-analysis. *Eur J Emerg Med,* **21**(2), 81-88.

Bourassa, S., Bouchard, P.-A., & Lellouche, F. (2018). Impact of gas masks on work of breathing, breathing patterns, and gas exchange in healthy subjects. *Respir Care,* **63**(11), 1350.

Byrne, A. L., Bennett, M., Chatterji, R., Symons, R., Pace, N. L., & Thomas, P. S. (2014). Peripheral venous and arterial blood gas analysis in adults: are they comparable? A systematic review and meta-analysis. *Respirology,* **19**(2), 168-175.

Chandrasekaran, B., & Fernandes, S. (2020). Exercise with facemask; Are we handling a devil's sword?– A physiological hypothesis. *Medl Hypotheses,* **144**, 110002.

Chesta, F., Jaruvongvanich, V., Gupta, R., Dayyeh, B. K. A., Singh, A., Singh, P. G., ...Buttar, N. S. (2021). Sa112 ventilated N95 respirators reduce CO_2 rebreathing and have better acceptability. *Gastroenterology,* **160**(6), S-425.

Chu, D. K., Akl, E. A., Duda, S., Solo, K., Yaacoub, S., Schünemann, H. J., ... Loeb, M. (2020). Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: A systematic review and meta-analysis. *Lancet,* **395**(10242), 1973-1987.

Department of Physical Education. (2020). *Report on the results of a survey on exercise or sports of people in Thailand.* Available at https://www.dpe.go.th/manual-files-432891791793

Douglas, M., Katikireddi, S. V., Taulbut, M., McKee, M., & McCartney, G. (2020). Mitigating the wider health effects of covid-19 pandemic response. *BMJ,* **369**.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behav Res Methods,* **41**(4), 1149-1160.

Fikenzer, S., Uhe, T., Lavall, D., Rudolph, U., Falz, R., Busse, M., ... Laufs, U. (2020). Effects of surgical and FFP2/N95 face masks on cardiopulmonary exercise capacity. *Clin Res Cardiol*.

Hendrix, M. J. (2020). Absence of apparent transmission of SARS-CoV-2 from two stylists after exposure at a hair salon with a universal face covering policy—Springfield, Missouri, May 2020. *MMWR Morb Mortal Wkly,* **69**.

IBM Corporation. (2019). IBM SPSS version 26. *Software.*

Jang, S., Han, S. H., & Rhee, J.-Y. (2020). Cluster of coronavirus disease associated with fitness dance classes, South Korea. *Emerg Infect Dis,* **26**(8), 1917.

Jones, N. R., Qureshi, Z. U., Temple, R. J., Larwood, J. P., Greenhalgh, T., & Bourouiba, L. (2020). Two metres or one: what is the evidence for physical distancing in covid-19? *BMJ,* **370**.

Kim, J.-H., Benson, S. M., & Roberge, R. J. (2013). Pulmonary and heart rate responses to wearing N95 filtering facepiece respirators. *Am J Infect Control* **41**(1), 24-27.

Lauren, B., Monroe, K., Nguyen, T., Suleiman, F., Tran, K., & Tran, V. (2015). Physiological change through aerobic exercise under hypoxic conditions with an elevation mask.

Liu, H., Zhang, X., Zhang, H., Yao, X., Zhou, M., Wang, J., . . . Mao, W. (2018). Effect of air pollution on the total bacteria and pathogenic bacteria in different sizes of particulate matter. *Environ Pollut,* **233**, 483-493.

Panawala, L. (2018). Difference between internal and external respiration, 2-4. Retrieved from https://www.researchgate.net/publication/318305698_Difference_Between_Internal_and_External_Respiration

Patel S, & Sharma S. (2022). *Respiratory Acidosis* (Updated: 21 June 2021). StatPearls [Internet]: StatPearls

Sellers, J. H., Monaghan, T. P., Schnaiter, J. A., Jacobson, B. H., & Pope, Z. K. (2016). Efficacy of a ventilatory training mask to improve anaerobic and aerobic capacity in reserve officers' training corps cadets. *J Strength Cond Res,* **30**(4), 1155-1160.

Shaw, K., Butcher, S., Ko, J., Zello, G. A., & Chilibeck, P. D. (2020). Wearing of cloth or disposable surgical face masks has no effect on vigorous exercise performance in healthy individuals. *Int J Environ Res Public Health,* **17**(21), 8110.

World Health Organization. (2021). *Global Tuberculosis Report 2021*. In: file:///C:/Users/Asus/Downloads/9789240037021-eng.pdf

World Health Organization. (2022). WHO Coronavirus (COVID-19) Dashboard. Retrieved 18 July 2022 https://covid19.who.int/

World Health Organization Thailand. (2019). air-pollution. Retrieved form https://www.who.int/docs/default-source/thailand/air-pollution/briefing-on-air-pollution-th-thai.pdf?sfvrsn=408572d4_2

Zouboules, S. M., Lafave, H. C., O'Halloran, K. D., Brutsaert, T. D., Nysten, H. E., Nysten, C. E., . . . Day, T. A. (2018). Renal reactivity: acid-base compensation during incremental ascent to high altitude. *J Physiol,* **596**(24), 6191-6203.