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The $PM_{2.5}$ concentration reduction due to the COVID-19 isolation measures influence the health risk during exercise

Bruna Marmett[a,*], Roseana Böek Carvalho[a], Gilson Pires Dorneles[b], Igor Martins da Silva[b], Pedro Roosevelt Torres Romão[b], Ramiro Barcos Nunes[c], Cláudia Ramos Rhoden[a]

[a]Laboratory of Atmospheric Pollution, Graduate Program in Health Science, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil
[b]Laboratory of Cellular and Molecular Immunology, Graduate Program in Health Science, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil
[c]Research Department – Instituto Federal de Educação, Ciência e Tecnologia Sul-rio-grandense, Gravataí, Brazil

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ABSTRACT

The practice of exercise led to increased inhalation of air pollution, being the concentration of pollutants an important factor that modulates the exposure. This study aimed to investigate the health risk of exercising in two different air pollution scenarios: before and after the implementation of COVID-19 restrictive measures. Forty-five healthy males performed a cardiopulmonary exercise test to determine the VE of the first and second threshold. Total ventilation of a 5 km endurance exercise hypothetical session performed at moderate- and high-intensity was estimated. The concentration of $PM_{2.5}$ was monitored to estimate the inhalation of pollution during the exercise sessions. Health risk assessment of performing moderate- and high-intensity exercise was calculated. High-intensity exercise had higher VE ($p<0.001$), VO_2 ($p<0.001$), speed ($p<0.001$), and VE_{TOTAL} ($p<0.001$). The inhalation of $PM_{2.5}$ and the health risk were higher during high-intensity exercise performed before restrictive measures ($p<0.001$). Therefore, the health risk of the exercise practice was higher in the air quality scenario before restrictive measures.

Redução na concentração de MP2,5 causada pelas medidas de isolamento para contenção do COVID-19 influenciaram o risco à saúde durante a prática de exercício

Palavras-chave:
Poluição do ar; monitoramento ambiental; exercício físico; medição de risco.

RESUMO

A exposição à poluição atmosférica pode ser maior durante a prática de exercício físico, considerando o aumento da frequência ventilatória e da inalação de poluentes durante esta prática. A concentração de poluentes no ar é considerada um fator crucial na modulação da exposição durante o exercício. Este estudo objetivou investigar o risco a saúde de realizar exercício em dois diferentes cenários de concentrações de poluentes atmosféricos: antes e depois da implementação das medidas restritivas para contenção da disseminação do COVID-19. Foram selecionados quarenta e cinco indivíduos do sexo masculino e saudáveis. Todos os participantes realizaram o teste de capacidade cardiopulmonar para determinar a ventilação por minuto dos limiares ventilatórios. Foi estimada a ventilação total de sessões hipotéticas de exercício de 5km realizadas com intensidade moderada e alta. A concentração de $MP_{2,5}$ foi monitorada visando estimar a inalação de poluentes presentes no ar durante o exercício. A avaliação de risco à saúde foi calculada em todas as sessões hipotéticas de exercício. O exercício de alta intensidade apresentou maior ventilação por minuto (VE) ($p<0,001$), volume de oxigênio (VO_2) ($p<0,001$), velocidade ($p<0,001$) e ventilação total (VE_{TOTAL}) ($p<0,001$). A inalação de $MP_{2,5}$ e o risco à saúde foram maiores durante o exercício de alta intensidade realizado antes da implementação das medidas restritivas. Portanto, o risco à saúde da inalação de $MP_{2,5}$ durante a prática de exercício foi maior no cenário com pior qualidade do ar.

1. Introduction

* Autor correspondente: brumarmett@hotmail.com (Marmett B.)

The coronavirus disease 2019 (COVID-19) pandemic emerged as a global emergency and resulted in severe consequences in all societies, including a negative impact on social, political, economic, and health scopes (1). One of the most important characteristics of SARS-CoV-2 is its quickly spread among people, being necessary to limit close contact with infected people. To reduce the spread of the virus, governments have recommended measures of social distancing, which also included self-isolation (1). These actions included the closure of schools, temples, churches, and workplaces, restricting public transport and commuting of people, and canceling domestic and international flights (2, 3). The implementation of lockdown and social distancing measures substantially reduced vehicle fleet and industrial processes, reducing air pollutant emissions by anthropogenic activities, and affecting air quality worldwide (4-8).

Air pollution is considered the largest environmental risk factor for human health, due to its contribution to the development of pulmonary, cardiovascular, and neurological diseases, and mortality (9-13). Specifically, exposure to fine particulate matter ($PM_{2.5}$) is associated with cardiopulmonary mortality, cerebrovascular events, and overall mortality (10, 12, 14). The principal source of $PM_{2.5}$ is vehicle emissions, being urban areas with a high vehicular fleet, as the capital city Porto Alegre (Brazil) locations with increased emissions and the population more vulnerable to the effects of this pollutant (15-17). The exercise practice in polluted environments could lead to higher inhalation of pollutants in response to physiological adaptations of exercise (18). The benefits of exercise could counteract the damage caused by the additional exposure to air pollution or result in detrimental health effects, being some conditions especially crucial on influencing the health risk during exercise in a pollutant environment (19-21). Among the factors that could modulate the inhalation of air pollutants during exercise are personal individualities and environmental features (17, 22). As observed in previous studies from our research group, individuals with higher body mass had increased total ventilation that resulted in incremental air pollution exposure, as well as, performing exercise in places and moments of the day with a higher concentration of pollutants (17, 22).

Two air pollution scenarios emerged in response to the implementation of restrictive measures: before the implementation, characterized by higher air pollution levels, and after the measures, potentially with lower levels of air pollution. Therefore, it was possible to analyze the health risk of exercise practice in a real-world environment of air pollution reduction. So, we performed a cross-sectional study aiming to investigate the health risk of exercising in a scenario of higher and lower air pollution.

2. Materials and Methods

Subjects

This cross-sectional study enrolled forty-five healthy sedentary young men (age: 27.58 ± 6.76 years; BMI: 22.73 ± 1.93kg/m²). Participants were healthy, no smokers, age ranging from 20 to 40 years, free of illness and injury, and not engaged in physical training programs for six months before the experimental trial. Exclusion criteria included excessive alcohol intake (>10 drinks/week), orthopedic limitations; neuromuscular or joint injury, autoimmune or cardiac diseases, or type 1 or type 2 diabetes, and acute and chronic infections.

The study was approved by the Ethics Research Committee of the Federal University of Health Science of Porto Alegre (UFCSPA) (63282416.6.0000.5345), and all experimental procedures were performed according to the Declaration of Helsinki. All participants were informed of the benefits and risks of the investigation before signing the institutionally approved informed consent to participate in the study. Participants were recruited from local universities via advertisements and oral communications. The data collection was carried out at the Human Movement Laboratory of UFCSPA, located at Porto Alegre City. Body mass (kg) and height (m) were determined by a semi-analytical scale with a stadiometer attached (Welmy, Santa Barbara D'Oeste, Brazil) before the cardiopulmonary exercise testing. The data collected were used to estimate the minute ventilation, total ventilation, and inhalation of the pollutant of the hypothetical exercise sessions described below.

Cardiopulmonary Exercise Testing (CPX)

All participants performed the CPX on an electric treadmill (Centurion 300) using a ramp protocol (23). The laboratory temperature (18 to 22°C) and relative humidity (40% to 60%) were continuously monitored. Briefly, the exercise test started at 4.5 km/h and with no slope for all studied participants. Then, the load (speed and slope) was individually increased for each participant considering their physical condition and tolerance. Ventilatory and metabolic parameters were collected by respiration using Metalyzer 3B (Germany). The CPX system was calibrated before each test concerning both airflow and O_2 and CO_2 analyzers. The test was terminated after verification of at least two of the following circumstances: (a) request of the participant due to extreme tiredness and/or perception of the intense dyspnea, being incapable to continue with the exercise; (b) reached the maximum heart rate (HR) predicted by age (HRmax) was ≥85%, indicating the maximum cardiorespiratory capacity; (c) peak respiratory exchange ratio RER > 1.1, which represents maximum effort during exercise; (d) VO_2 plateau was reached even with an increasing workload, reaching the maximal oxygen uptake or maximal aerobic capacity (23).

The VO_{2peak} was determined as the average of the last test 30 seconds. The first ventilatory threshold (VT_1) was identified as the minimum workload at which the ventilatory equivalent ratio for oxygen (VE/VO_2) systematically increased without an increase in the ventilatory equivalent ratio for carbon dioxide (VE/VCO_2), and the second ventilatory threshold (VT_2) as the lowest workload where both VE/VO_2 and VE/VCO_2 increased (23). VT_1, VT_2, and VO_{2max} were obtained by visual inspection of graphs by 3 independent observers. Data extracted from CPX was applied to predictive equations to estimate total ventilation and air pollution inhaled dose during hypothetical exercise sessions.

Air Pollution Concentration

We monitored the concentration of fine particulate matter ($PM_{2.5}$) in Porto Alegre, the capital of the southernmost state of Brazil, Rio Grande do Sul, located at sea level, with 10 m altitude, latitude 30.01 S, and longitude 51.13 W (Google Maps) and calculated the daily mean concentration of this pollutant aiming to achieve a pattern of air pollution concentration in the city. $PM_{2.5}$ was continuously measured with a 10-sec resolution by automated fixed stations which system is part of a project entitled "Porto Ar Alegre. Five monitoring points were distributed in Porto Alegre to have a panorama of air pollutants and achieve spatial coverage throughout the city, considering sites with different population profiles, range of traffic conditions, size and number of buildings, and poverty levels. The five points were: Point 1) Basic Health Unit (UBS) Costa and Silva: at Rubem Berta neighborhood, with 87,367 inhabitants and a higher rate of poverty, contains the Porto Seco Complex, which results in the movement and traffic of 18 million tons of cargo per year by heavy vehicles; Point 2) Federal University of Health Science of Porto Alegre (UFCSPA): at Centro Histórico neighborhood, a central area of the city with 37,000 inhabitants; Point 3) Clinical Hospital of Porto Alegre (HCPA): at Santa Cecília neighborhood, with 5,768 inhabitants, characterized by a high flow; Point 4) UBS Humaitá: located at Humaitá neighborhood, a residential area with 11,404 inhabitants and surrounded by a great number of industries; Point 5) UBS

Restinga, at Restinga neighborhood, with 60,729 inhabitants, located in the extreme south of the city with high rates of poverty.

The monitoring period included 30 days before the implementation of restrictive measures (Non-pandemic: February 14th to March 15th of 2020) and 30 days after it (Pandemic: March 16th to April 14th of 2020). We calculated the daily mean of $PM_{2.5}$ in the five monitoring points and then compared the 30 days before and after the implementation of the restrictive measures. Meteorological parameters of temperature, humidity, wind speed, precipitation, and solar radiation were accessed during the air pollution monitoring period in the National Institute of Meteorology (INMET).

Prediction of Total Ventilation and Pollutants Inhalation during Exercise

To predict the VE_{TOTAL}, minute ventilation (VE, L/min) was extracted at VT_1 and VT_2 identified in each participant CPX, representing the moderate- and high-intensities of exercise, respectively. The intensities were used based on moderate-intensity and high-intensity endurance exercise recommendations (24) but with equalized volume (5 km). The volume of the exercise was equalized considering the time required to complete a 5 km exercise with the speed (km/h) identified in each VT_1 and VT_2. Thus, the VE_{TOTAL} of two hypothetical 5 km endurance exercise sessions was predicted using Equation A:

VE_{TOTAL} (L) = VE (L.min^{-1}) × time spent to complete 5 km at each ventilatory threshold intensity

Further, the VE_{TOTAL} values were used to calculate the inhaled dose of $PM_{2.5}$ (25), during the hypothetical exercise sessions in both intensities considering the $PM_{2.5}$ concentrations before and after the restrictive measures against the spread of COVID-19, according to Equation B:

$$\text{Pollutant inhaled } (\mu g) = VE_{TOTAL} \times \text{pollutant concentration } (\mu g/m^3)/1000$$

In which, pollutant inhaled is the total amount of pollutant inhaled during the exercise, VE_{TOTAL} is the total ventilation during the two hypothetical endurance exercise sessions, and pollutant concentration is the concentration of the air pollutant measured in Porto Alegre city before and after restrictive COVID-19 measures.

Health Risk Assessment

The health risk was estimated based on the potential intake dose of the pollutants and the reference dose. We considered the risk of performing 30 minutes of running, 5 days/week with the first and second threshold intensities in an environment with $PM_{2.5}$ concentration equal to the city of Porto Alegre before (non-pandemic) and posterior (pandemic) the implementation of social isolation. Equation C of the United States Environmental Protection Agency (USEPA) was used to calculate the potential intake dose for both situations (I, µg/kg.day) considering (26):

$$I = C_A \text{ x } ((IP \text{ x } FR \text{ x } FA \text{ x } ET \text{ x } EF \text{ x } ED)/BW) \text{ x } 1/AT$$

C_A = average $PM_{2.5}$ concentrations of monitored days (µg/m^3)

IP = inhalation rate (m^3/h)

FR = retention factor - we assumed a retention factor of FR = 1, which represents the highest exposure and the highest potential impact on subjects' health

FA = absorption factor - we assumed an absorption factor of FA = 1, which represents the highest exposure and the highest potential impact on subjects' health

ET = exposure time (h/d) – exercise´s duration
EF = exposure frequency (d/y): 5 times/week - 20 time/month – 260 days/year
ED = duration of exposure (y): 260 days of exposure/365 days = 0.71
BW = body weight (kg)
AT = average time - the period of exposure in which the dose was measured (d): 30
The risk quotient (RQ) = I/ RfD
In which:
I = potential intake dose (µg/kg.day);
RfD: reference dose for $PM_{2.5}$ = 1.14, according to Collins and colleagues (2004) (27) and Silva and colleagues, 2016 (28).

Risk quotients are classified as follows: RQ ≤ 1: unlikely risk, even in population groups that are sensitive to adverse health effects; RQ > 1: there is a risk of non-carcinogenic adverse effects on human health (26).

Statistical Analyses

The normality of the data was measured using the Shapiro-Wilk test. Unpaired Student t-test was used to compare intensities of exercise for the variables of ventilation rate, VO_2, speed, duration of the session, and VE_{TOTAL}, and to compare $PM_{2.5}$ concentrations in the non-pandemic and pandemic period. A 1-way analysis of variance (ANOVA) followed by Bonferroni's post-hoc test was applied to compare $PM_{2.5}$ inhalation, potential intake dose of pollution, and coefficient risk among moderate and high-intensity exercises performed in the non-pandemic and pandemic period. All analyses were performed using SPSS 20.0 (SPSS Inc., EUA). The significance level was set at $p \geq 0.05$.

3. Results

Regarding the parameters evaluated during the hypothetical exercise session, the high-intensity exercise had higher VE ($p<0.001$), VO_2 ($p<0.001$), speed ($p<0.001$), and VE_{TOTAL} ($p<0.001$) compared to the moderate-intensity. While the duration to complete a 5km endurance exercise was higher in moderate-intensity than in high-intensity ($p<0.001$) (Table 1).

Table 1 – Physiological parameters of moderate-intensity and high-intensity endurance exercise.

	Moderate-intensity (n=45)	**High-intensity** (n=45)	***p value***
VE (L/min)	38.98 ± 13.07	75.15 ± 18.57*	<0.001
VO_2 (mL/kg min)	24.99 ± 6.553	39.83 ± 7.655*	<0.001
Speed (km/h)	7.911 ± 1.043	11.30 ± 1.811*	<0.001
Hypothetical exercise session			
Exercise duration (min)	38.60 ± 5.306	27.24 ± 4.437*	<0.001
VE total (L)	1,469 ± 443.7	2,016 ± 536.2*	<0.001

VE: minute ventilation; VO_2: volume of oxygen; VE_{total}: total ventilation.
Data are presented as mean ± SD. Difference between groups verified by Student t-test ($p<0.05$).
* Denotes statistical difference compared to moderate-intensity group ($p<0.05$).

$PM_{2.5}$ concentration had higher levels in the non-pandemic period compared to the pandemic period ($p<0.0051$). Meteorological parameters of temperature ($p=0.0002$), humidity ($p=0.0015$), and UV radiation ($p<0.001$) were higher during the non-pandemic compared to the pandemic period, while wind speed ($p=0.5985$) and precipitation ($p=0.9969$) demonstrated no difference between those periods (Table 2).

Table 2 – $PM_{2.5}$ concentration and the meteorological parameters during the period of monitoring.

	Non-pandemic February 14th – March 15th	**Pandemic March 16th – April 14th**	***p-value***
$PM_{2.5}$ concentration (µg/m³)	12.27 ± 8.535*	9.573 ± 5.585	0.0051
Temperature (°C)	24.72 ± 2.671*	21.99 ± 2.691	0.0002
Humidity (%)	67.12 ± 5.524*	72.78 ± 7.450	0.0015
Wind speed (m/s)	1.552 ± 0.2714	1.610 ± 0.5288	0.5985
Precipitation (mm)	0.0731 ± 0.2763	0.0733 ± 0.1356	0.9969
UV radiation (KJ/m²)	1,739 ± 318.8*	1,308 ± 385.7	<0.001

February 14th – March 15th: the period before COVID-19 restrictive measures; March 16th – April 14th: the period posterior COVID-19 restrictive measures.
Data were accessed in National Institute of Meteorology (INMET).
Data are presented as mean ± SD. Difference between groups verified by Student t-test ($p<0.05$).
* Denotes statistical difference compared to Pandemic period (March 16th – April 14th) ($p<0.05$).

The inhalation of $PM_{2.5}$ was higher during the high-intensity exercise performed in a non-pandemic period compared to moderate-intensity performed in non-pandemic and pandemic periods ($p<0.001$). Also, moderate-intensity exercise performed in the non-pandemic period and high-intensity exercise performed in the pandemic period led to higher $PM_{2.5}$ inhalation compared to moderate-intensity exercise in the pandemic period ($p<0.001$) (Figure 1).

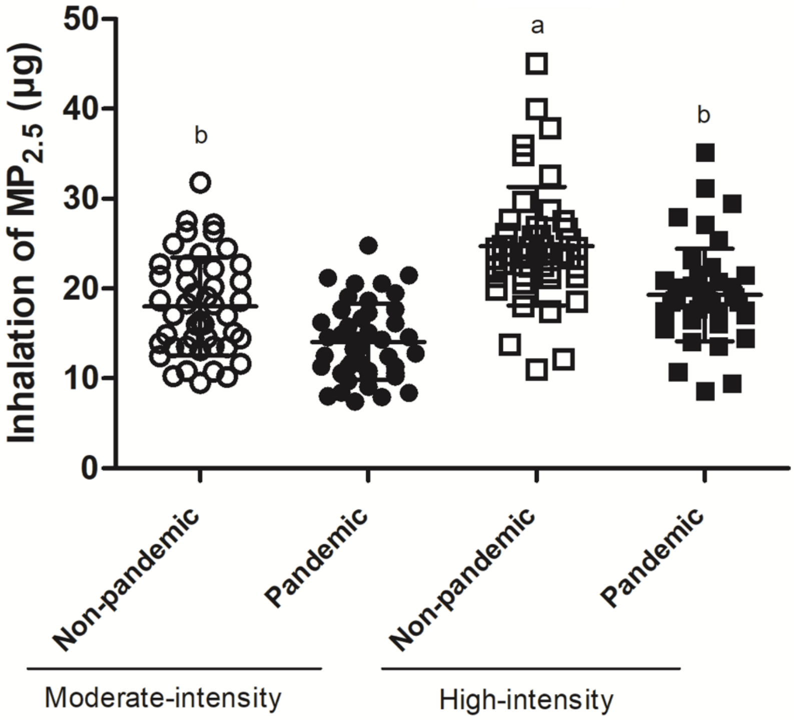

Figure 1 – Inhalation of $PM_{2.5}$ during moderate-intensity and high-intensity endurance exercise in Porto Alegre city. Data are presented as mean ± SD. Between groups, differences were verified by one-way ANOVA followed by Bonferroni's post hoc ($p<0.05$). [a]Denotes statistical difference compared to moderate-intensity exercise performed during the non-pandemic period and moderate- and high-intensity exercise performed during the pandemic period ($p<0.05$); [b]Denotes statistical difference compared to moderate-intensity exercise performed during the pandemic period ($p<0.05$).

Regarding the potential intake dose of the air pollutant and the health risk, the high-intensity exercise performed in the non-pandemic period demonstrated higher levels compared to moderate-intensity exercise in non-pandemic and pandemic periods, and high-intensity exercise performed in pandemic period ($p<0.001$). The moderate-intensity exercise performed during the non-pandemic period and the high-intensity exercise performed in the pandemic period showed higher potential intake dose and risk quotient than moderate-intensity performed during the pandemic period ($p<0.001$) (Figure 2).

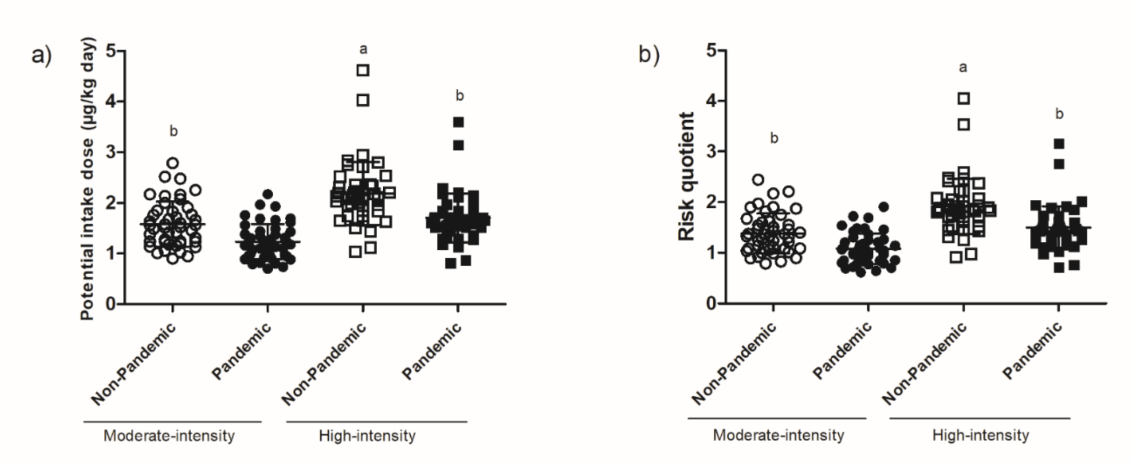

Figure 2 – Health risk of performing moderate-intensity and high-intensity endurance exercise in non-pandemic and pandemic periods. a) Potential intake dose of $PM_{2.5}$. b) Risk quotient. Data are presented as mean ± SD. Between groups, differences were verified by one-way ANOVA followed by Bonferroni's post hoc ($p<0.05$). [a]Denotes statistical difference compared to moderate-intensity exercise performed during the non-pandemic period and moderate- and high-intensity exercise performed during the pandemic period ($p<0.05$); [b]Denotes statistical difference compared to moderate-intensity exercise performed during the pandemic period ($p<0.05$).

4. Discussion

Our results demonstrated higher VE and VE_{TOTAL} in high-intensity endurance exercise, while moderate-intensity demanded a higher duration to complete the exercise session compared to high-intensity. The $PM_{2.5}$ concentration had higher levels before the implementation of restrictive measures. Therefore, a high-intensity exercise performed before isolation measures resulted in the highest $PM_{2.5}$ inhalation, potential intake dose, and, consequently, health risk.

The high-intensity exercise resulted in higher VE, speed, VO_2, and VE_{TOTAL} compared to moderate-intensity. Once the moderate-intensity had a lower speed, the duration of the exercise was higher than in high-intensity. Considering that both VE and duration were used on the VE_{TOTAL} prediction, the higher VE values of exercising in high-intensity overwhelm the extra time spent during the moderate-intensity session. It is well known that exercise performed at a higher intensity resulted in the augment of VE_{TOTAL} and, consequently, in an increased inhalation of air pollution (18, 22, 29).

In our study, the concentration of $PM_{2.5}$ was higher before the implementation of restrictive measures when compared to the period after it. The decrease in air pollutants concentration occurred because of the actions and measures to minimize SARS-CoV-2 transmission implemented by governments around the world, including Porto Alegre authorities (2, 3). Besides the reduction of the emission sources of $PM_{2.5}$, the temperature, humidity, and UV radiation were lower during the pandemic period, which could have contributed to the increased air pollution concentration in the non-pandemic period. It is well known that meteorological parameters influence the concentration of air pollutants, the low temperature is associated with thermal inversion that causes a higher concentration of pollutants like $PM_{2.5}$ in the air. Also, the increased humidity leads to the reduction of ascendant airflow and lower temperatures that increase the concentration of air pollutants (30-33). The reduction in the concentration of $PM_{2.5}$ observed in our study agrees with other works conducted in Brazil and worldwide that reported mitigation of air pollution during COVID-19 lockdown compared to before the period due to the reduction in anthropogenic emissions (34-38). Porto Alegre is a city with a large number of parks and green areas, ideal places to realize physical activities, and the policies to control SARS-CoV-2 spreading did not include the closing of these specific locals (39). Thereby, it was possible for the population to maintain the routine of outdoor exercises and to benefit from the decrease in air pollutants concentration.

The high-intensity exercise performed in the non-pandemic period led to higher inhalation of $PM_{2.5}$ since the concentration of the pollutant and VE_{TOTAL} were increased under those conditions. Considering the augmented concentration in $PM_{2.5,}$ the moderate-intensity exercise in the non-pandemic period had increased air pollutant inhalation compared to the same intensity in the pandemic period. Posterior to implementation of the restrictive measures, high-intensity exercise led to higher inhalation compared to moderate-intensity. Moreover, it was observed an absence of difference between moderate-intensity exercise performed in a non-pandemic period compared to high-intensity exercise during the pandemic period, since the VE was higher in high-intensity exercise, but the concentration of $PM_{2.5}$ was decreased in the pandemic period. These findings contribute to the literature that indicated the intensity of exercise as a determinant to the total ventilation of an exercise session, and directly influencing the inhalation of pollutants (22, 40, 41).

Additionally, the potential intake dose and health risk were higher during high-intensity exercise in the non-pandemic period. The reduction of health risk during exercising in the pandemic period occurred due to the improvement of air quality in response to the actions to minimize the transmission of SARS-CoV-2. It is worth noting that the concentration of $PM_{2.5}$ did not exceed the WHO standards and despite the slight decrease in the levels it represented an important reduction in health risk (42). A previous study from our research group demonstrated environmental health risk in individuals performing 30 minutes of high-intensity exercise in a concentration of $PM_{2.5}$ above 115μg/m^3 and after 120 minutes of a high-intensity exercise in a $PM_{2.5}$ concentration of 40.64 μg/m^3 (22). The intensity of the exercise influenced the potential intake dose and the risk quotient, indicating that both concentration of air pollution and intensity of exercise is important and decisive variables that influence the inhalation of air pollutants (17, 22). Additionally, the risk-benefit balance between physical activity and exposure to air pollution was assessed in the studies of Tainio and colleagues and Pasqua and colleagues, which demonstrated that the relative risk of 75 min of running with moderate-intensity in cities with high levels of $PM_{2.5}$, and 30 min of cycling at a $PM_{2.5}$ concentration of 160 μg/m^3 would overcome the benefits of exercise (25, 43).

The decrease in $PM_{2.5}$ concentration and consequently in the health risk might represent a great impact on public health, considering the hypothesis that fewer particles in the air could reduce the transmission of the virus and that the long-term exposure to $PM_{2.5}$ increase the susceptibility of the population to COVID-19, resulting in more severe cases (44, 45). A study by Leão and colleagues that evaluates the health impact assessment in a Brazilian capital demonstrated that if the reduction in $PM_{2.5}$ concentration observed in the lockdown was maintained 106 annual deaths from non-external causes and 58 annual deaths from cardiovascular diseases would be avoided, summing to $ 294.88 million saved (34). Therefore, policies to reduce the air pollution emissions must be implemented aiming to avoid public health crises assuring a better quality of life for the population and reduction in the public costs on health.

To the best of our knowledge, the estimation specifically of the environmental health risk during exercise is an emerging topic with a little number evidence, and we believe this work could contribute to this field of research. As a limitation of the present study, we did not evaluate the concentration of NO_2, which is the pollutant that demonstrated the most prominent reduction during the period of restrictive measures due to its direct relationship with vehicle traffic. Also, we had enrolled in our study 45 individuals, which could be a limited sample size and they were not stratified by age in the analysis. Nevertheless, we assessed $PM_{2.5}$ through active methodology using multi-point monitors, providing a high-quality background of this pollutant in the city.

5. Conclusion

In conclusion, this study used restrictive measures to contain the spread of COVID-19 to evaluate the health risk of hypothetical exercise practice in two scenarios characterized by higher and lower air pollution concentrations. The health risk was superior during a high-intensity exercise session performed in the most polluted environment. Therefore, our results reinforced the necessity to reduce the emission of air pollutants to lower the health risk and could be applied as evidence to base exercise recommendations, as air pollution concentration and intensity of exercise had a greater influence on the health risk.

Declarations of interest: None

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