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Effect of Wearing Face Masks on the Carbon Dioxide Concentration in the Breathing Zone

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ABSTRACT

The use of face masks is among the measures taken to prevent person-to-person transmission of the virus (SARS-CoV-2) responsible for the coronavirus disease (COVID-19). Lately, concern was expressed about the possibility that carbon dioxide could build up in the mask over time, causing medical issues related to the respiratory system. In this study, the carbon dioxide concentration in the breathing zone was measured while wearing a surgical mask, a KN95 and a cloth mask. For the surgical mask, the concentration was determined under different conditions (office work, slow walking, and fast walking). Measurements were made using a modified indoor air quality meter equipped with a nondispersive infrared (NDIR) CO_2 sensor. Detected carbon dioxide concentrations ranged from 2150 ± 192 to 2875 ± 323 ppm. The concentrations of carbon dioxide while not wearing a face mask varied from 500–900 ppm. Doing office work and standing still on the treadmill each resulted in carbon dioxide concentrations of around 2200 ppm. A small increase could be observed when walking at a speed of 3 km h^{-1} (leisurely walking pace). Walking at a speed of 5 km h^{-1}, which corresponds to medium activity with breathing through the mouth, resulted in an average carbon dioxide concentration of 2875 ppm. No differences were observed among the three types of face masks tested. According to the literature, these concentrations have no toxicological effect. However, concentrations in the detected range can cause undesirable symptoms, such as fatigue, headache, and loss of concentration.

Keywords: Face masks, Carbon dioxide, SARS-CoV-2, COVID-19 pandemic, COVID-19

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1 INTRODUCTION

Physical distancing, good hand hygiene and the wearing of gloves and face masks are among the most frequent measures taken to prevent person-to-person transmission of the virus (SARS-CoV-2) responsible for the coronavirus disease (COVID-19) since the outbreak of the COVID-19 pandemic in early 2020 (Chu *et al.*, 2020; Howard *et al.*, 2020). Especially, the use of face masks in public reduces the spread of the virus by minimizing the excretion of respiratory droplets from asymptomatic infected individuals or individuals who have not yet developed symptoms (Bourouiba, 2020). The human body utilizes oxygen and generates carbon dioxide, which is then exhaled in the expiration air. An adult with healthy lungs produces approximately 5.6% by volume of CO_2. When wearing a face mask, a fraction of carbon dioxide previously exhaled is inhaled again with each respiratory cycle. Some media have been claiming that carbon dioxide may slowly build up in the mask over time, causing medical issues related to the respiratory system such as hypercapnia (a condition arising from too much carbon dioxide in the blood).

Only a few studies have been conducted so far in this field. In a study conducted by Sinkule *et al.* (2013), the breathing air quality when using N95 filtering facepiece respirators was assessed. The concentration of carbon dioxide increased to approximately 1.2–3% in a short period of light work. The participants did not show any obvious changes in physical functions. The average carbon dioxide concentration inhaled was, however, far higher than the limit of 0.1% of indoor carbon dioxide concentration in many countries. The study of Li *et al.* (2005) investigated the effects of wearing N95 and surgical face masks with and without nano-functional treatments on thermo-physiological responses and the subjective perception of discomfort in five healthy participants (men and women). They found that surgical face masks were rated significantly lower for perceptions of humidity, heat, breath resistance and overall discomfort than N95 face masks. Carbon dioxide was not among the investigated parameters. The aim of the study conducted by Lim *et al.* (2006) was to determine the prevalence of headaches from the use of N95 face masks amongst healthcare workers. Approximately 40% of the participants reported face-mask-associated headaches. The study conducted by Roberge *et al.* (2010) assessed the physiological impact of N95 filtering face-piece respirators on healthcare workers. The parameters assessed included the concentration of carbon dioxide and oxygen in the mask's dead space. The detected carbon dioxide concentrations were around 3% (30000 ppm). Such high concentrations are typically associated with detrimental physiological effects such as headache, anxiety and confusion. In the study, the sampling was done via a sampling line attached to a port in the mask that was equidistant between the nose and the mouth and therefore probably measured the slightly diluted carbon dioxide concentration in the exhaled air rather than in the breathing zone. Another study explored the effects of face masks (cloth mask and paper face masks) on CO_2, heart rate, respiration rate and oxygen saturation on instructor pilots (Dattel *et al.*, 2020). Also in this study relatively high carbon dioxide concentrations (around 45000 ppm) were detected. The methodological description however does not allow the unequivocal identification of the exact sampling point, making it impossible to assess whether the measured concentrations refer to the exhaled air or to the breathing zone.

This study aimed to determine the concentration of carbon dioxide in the breathing zone while wearing a face mask. Three types of face masks were tested under different conditions (office work, slow walking and fast walking). The measured concentrations were compared against existing threshold values for critical levels of carbon dioxide.

2 MATERIALS AND METHODS

2.1 Tested Face Masks

Three different types of face masks were tested:

a) A medical face mask (also known as a surgical mask) conform with the European Union's health and safety standards (CE mark): This type of face mask is typically used by health care workers, ensuring a barrier that limits the transition of an infective agent between the hospital staff and the patient. During the COVID-19 pandemic, surgical face masks have been recommended as a means of source control for persons who are either symptomatic or asymptomatic to prevent the spread of respiratory droplets produced by coughing or sneezing. The application of medical masks as source control has been shown to decrease the release of respiratory droplets carrying respiratory viruses (Leung *et al.*, 2020) and they are recommended for the reduction of transmission of influenza (Cheng *et al.*, 2010; MacIntyre and Chughtai, 2015; MacIntyre *et al.*, 2015). Medical masks comply with requirements defined in European Standard EN 14683:2019 (European Committee for Standardization, 2019).
b) KN95 with a one-way valve: N95 is an American standard managed by NIOSH, which is part of the Centers for Disease Control (CDC). KN95 masks are the equivalent Chinese standard for masks. Both N95 and KN95 correspond to the FFP2 code used in the European Union (European Committee for Standardization, 2001) and protect against solid and liquid irritating aerosols with a minimum filter efficiency of 92%. The mask tested in this work included a one-way exhalation valve that makes it easier to breathe through. This type of mask is not recommended as an effective barrier against the SARS-CoV-2 virus because the valve releases unfiltered air when the wearer breathes out and therefore does not prevent the wearer from spreading the virus. It was included in the study to assess the potential impact of the exhalation valve on the concentration of accumulated carbon dioxide.
c) Cloth masks: Since surgical and FFP2 masks were sometimes difficult to find at the beginning of the pandemic and, especially the FFP2 masks should be reserved for health care providers, cloth masks have become popular during the pandemic as they are cheap, easy to find or to make and can be washed and reused. Cloth masks can be made from common materials, such as sheets made of tightly woven cotton, and should include multiple layers of fabric. There are no standards or regulations for self-made cloth face masks. The mask used in this study was

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manufactured by a northern Italian company that converted its production from sportswear to face masks during the pandemic. It was made of three layers: the internal and external layers were primarily made of polyamide, and the interior filter was made out of polyester.

2.2 Instrumentation

Carbon dioxide concentrations were measured with a TSI 7545 IAQ Meter (TSI Incorporated, Shoreview MN, USA) equipped with a low-drift dual-wavelength NDIR CO_2 sensor. This instrument has a declared measurement concentration range of 0–5000 ppm and an accuracy of ± 3.0% of reading or ± 50 ppm (whichever is greater). Its resolution is 1 ppm. The instrument was calibrated against a secondary carbon dioxide standard (470 ppm). All measurements were performed on the same day the instrument was calibrated.

2.3 Experimental Setup

The concentration of carbon dioxide in the breathing zone was determined by aspirating air through a silicon tube from the breathing zone behind the face mask. The sampling point was just above the nose tip on the bridge of the nose. In this way, the point of sampling was not located directly in the exhaled air stream while at the same time being completely covered by the face masks. Shifting of the silicon tube was prevented by fixing the tube to the bridge of the nose with some tape. It was then inserted through a perforated face shield holder. From there, the tube was directed over the head, where it was further fixed with a cap (Fig. 1).

The aspirated air was then conducted to the CO_2 sensor. The sensor-containing probe is usually directly exposed to the surrounding air in which the carbon dioxide concentration is measured. In this study, a collar that provides a closed area around the gas probe and that is normally used for calibration purposes was hermetically sealed with some tape to the lower part. A sampling point made of Teflon was integrated into the sealing tape. In this way, the air flow passed undiluted over the CO_2-sensor. A pump was connected to the end of the sampling train (Fig. 1(c)).

Fig. 1. Experimental setup. (A) Sampling point close to the nose tip; (B) Position of the sampling point while the face mask was worn; (C) Activity pattern ‘Office work’; (D) Activity pattern slow and medium speed walking on a treadmill.

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The concentration of carbon dioxide was measured for two activity patterns: in the first scenario the male, 50 year old volunteer was working on a computer, breathing through the nose and remaining seated for the duration of the measurements. Under these conditions, all three types of face masks were tested. In the second scenario, the volunteer was walking on a treadmill at 0, 3 and 5 km h^{-1}. While at 0 and 3 km h^{-1}, the volunteer was breathing through his nose, at 5 km h^{-1} he was breathing through his mouth. Each new condition was preceded by the registration of a baseline (the same condition but without the masks being worn). The sampling duration for each activity pattern was 5 minutes. The data collection frequency (sampling rate) was set at 1 s^{-1}.

3 RESULTS AND DISCUSSION

Fig. 2 shows the concentrations of carbon dioxide measured for all three types of face masks while working on the computer, remaining seated all the time and breathing through the nose. The concentrations were 2107 ± 168 ppm, 2293 ± 169 ppm and 2051 ± 238 ppm for the surgical, the KN95 and the cloth mask, respectively. No relevant difference in the detected carbon dioxide concentration could be observed among the three mask models. Even with the one-way exhalation valve on the KN95 face mask, under these conditions, the type of mask had no significant impact on the carbon dioxide concentration in the breathing zone. The baseline concentration, corresponding to those periods of time when no mask was worn, was 501 ± 42 ppm. The concentration of carbon dioxide in the breathing zone while wearing the face mask did therefore increase in average by approximately 1650 ppm.

Since no difference was observed among the types of face masks worn, in the second scenario (walking on a treadmill at different speeds), the measurements were made while wearing only the surgical mask. Fig. 3 depicts how the baseline concentration of CO_2 in this setting, compared to the office-activity setting, is slightly higher and how it slowly increases over time (737 ± 27 ppm

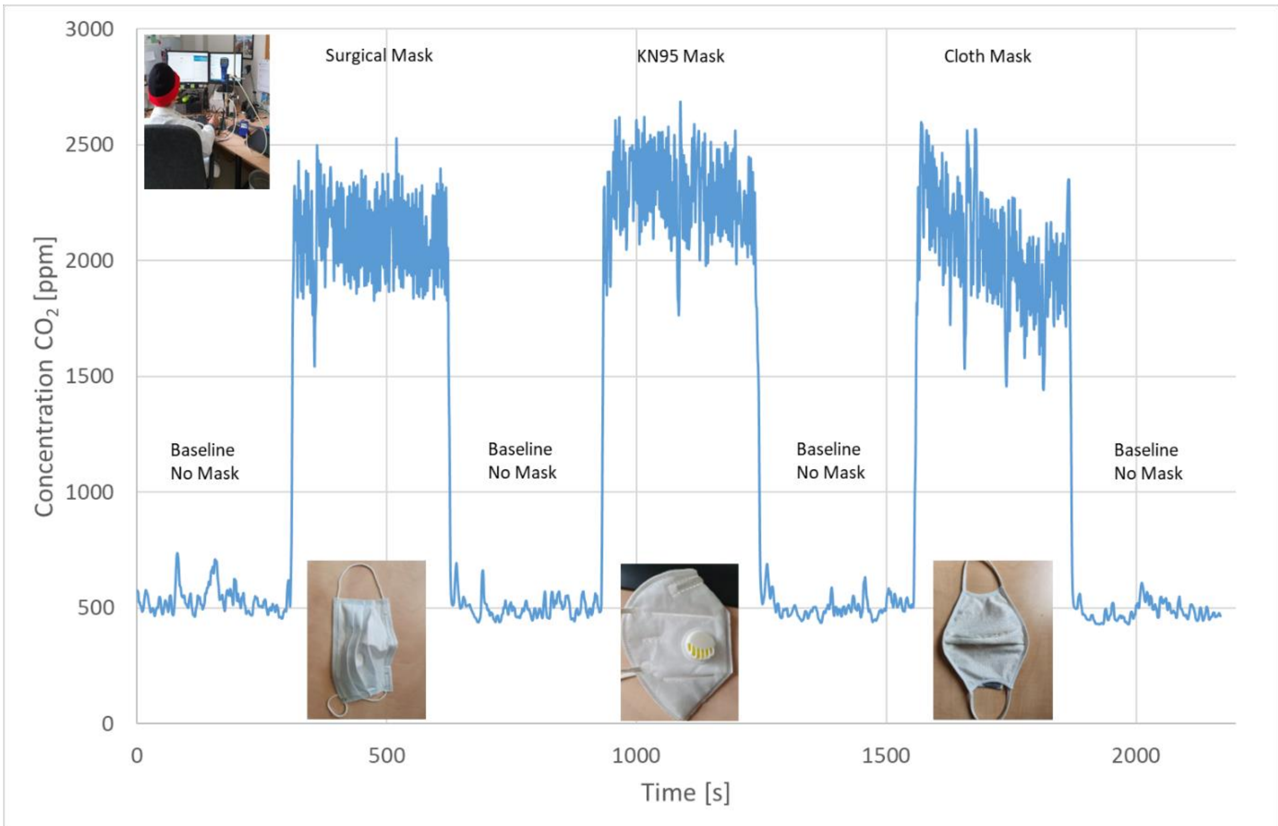

Fig. 2. Concentrations of carbon dioxide measured for all three types of face masks while working on the computer, remaining seated all of the time and breathing through the nose

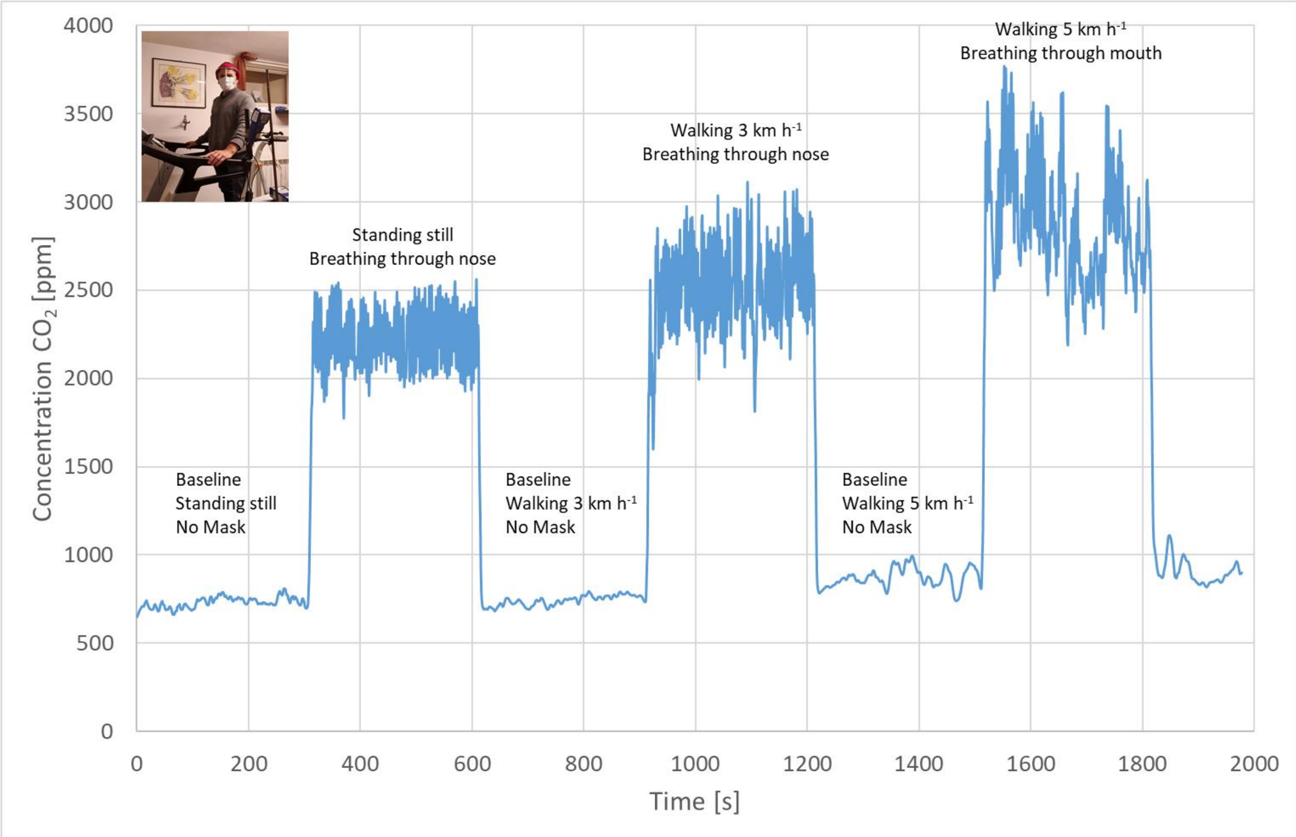

Fig. 3. Concentrations of carbon dioxide measured while walking on a treadmill at 3 and 5 km h^{-1}.

before 'standing still' measurements, 744 ± 24 ppm before 'walking at 3 km h^{-1} measurement and 890 ± 51 ppm before 'walking at 5 km h^{-1} measurement). This can be explained by the relatively small room in which the treadmill was located, which led to an enrichment of carbon dioxide from exhalation in the room. The average concentration of 2226 ± 165 ppm while standing still was, as expected, in the same range as the concentrations measured while doing office work. A small increase in concentration (2536 ± 245 ppm) could be observed while walking at a speed of 3 km h^{-1}. This speed corresponds to a leisurely walking pace (low activity). A further increase in the detected carbon dioxide concentration was observed while walking at 5 km h^{-1} (2875 ± 323 ppm), which corresponds to a higher walking pace (medium activity) with breathing through the mouth and an augmented breathing rate.

Inhaled carbon dioxide at lower concentrations (< 10000 ppm) has little or no toxicological effects. At higher concentrations (> 50000 ppm), it causes the development of hypercapnia and respiratory acidosis (Permentier *et al.*, 2017). A concentration of 5000 ppm is the workplace exposure limit (as 8-hour TWA) in most jurisdictions. Exposures to increased inhaled CO_2 concentrations between 2–3% (20000–30000 ppm) are known to produce sweating, headache and dyspnoea (Schneider and Truesdell, 1922). Inhaled concentrations between 4 and 5% (40000–50000 ppm) are associated with dyspnoea, increased blood pressure, dizziness, and headache (Schneider and Truesdale 1922; Schulte 1964). If inhaled CO_2 concentrations are at 5% (50000 ppm), mental depression may occur within several hours (Schulte, 1964).

The concentrations measured in this study are all far below these threshold values and range between 2150 ppm (office work) and 2875 ppm (walking at 5 km h^{-1}). Concentrations of CO_2 in this range and their association with health symptoms are frequently discussed in the context of the "sick building syndrome" (Apte *et al.*, 2000; Seppaenen *et al.*, 1999; Wargocki *et al.*, 2000). In a building, the carbon dioxide emissions are approximately proportional to the rise in odorous substances given off by human beings by perspiration. In rooms in which no combustion processes are taking place, the carbon dioxide concentration can therefore be regarded as an indicator of the indoor air quality. Carbon dioxide-related health-symptoms have been observed at concentrations above 1000 ppm and include drowsiness and loss of attention (Guais *et al.*, 2011). A portion of the human population has been described as being sensitive to fluctuating CO_2 concentrations. As a vasodilator, the effect on people prone to headache has also been discussed. For example, Lim *et al.* (2006) administered a survey to healthcare workers to determine risk factors associated with the development of headaches. Approximately 40% of the respondents reported wearing face masks was associated with headaches. This study did not, however, report the inhaled CO_2 concentrations. Satish *et al.* (2012) suggested in their study that even moderately elevated CO_2 concentrations (approximately 2500 ppm) have the potential to affect decision-making.

4 CONCLUSIONS

The concentrations of carbon dioxide measured in the breathing zone while wearing a face mask ranged between 2150 and 2875 ppm depending on the type of activity. The concentrations of carbon dioxide without wearing a face mask varied from 500–900 ppm, corresponding to normal carbon dioxide concentrations in indoor environments. Doing office work and standing still on the treadmill each resulted in carbon dioxide concentrations of around 2200 ppm. A small increase of approximately 300 ppm could be observed when walking at a speed of 3 km h^{-1} (leisurely walking pace). Walking at a speed of 5 km h^{-1}, which corresponds to medium activity with breathing through the mouth, resulted in an average carbon dioxide concentration of 2875 ppm. No differences were observed among the three types of tested face masks. According to the literature, these concentrations have no toxicological effect when inhaled. However, concentrations between 1,000 ppm and 10,000 ppm can cause undesirable symptoms such as fatigue, headache and loss of concentration. This may be relevant for those segments of the population required to wear face masks over prolonged periods of time such as students, bus drivers or cashiers as well as persons with respiratory diseases. Wearing face masks only when strictly necessary may reduce these undesired side effects.

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