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Particulate matter in air at indoor go-kart facilities in Bavaria, Germany

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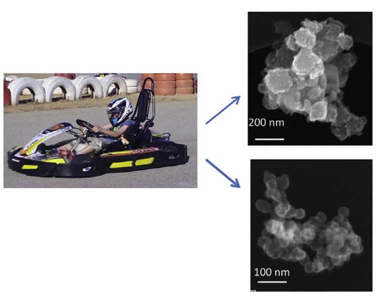
GRAPHICAL ABSTRACT



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ABSTRACT

Indoor go-karting is a popular free time activity for many people, including adults and children. Particulate matter from engine emissions, brake and tire debris and gaseous pollutants are important sources of air pollution. Exposure to these air pollutants is associated with health-related problems. In this study, the exposure of employees and spectators to particulate matter was measured in 8 indoor go-kart facilities (6 facilities used gasoline, one used liquid gas and one used electricity for their go-karts). The mass concentrations of particulate matter were continuously analyzed. Particles were sampled and analyzed by inductively coupled plasma mass spectrometry and electron microscopy coupled with energy-dispersive X-ray spectroscopy. The mean PM_{10} concentrations ranged between 4.9 and 34.9 µg/m^3 for workplaces and 5.6 and 28.4 µg/m^3 for spectator areas. The mean $PM_{2.5}$ concentrations measured in workplaces ranged from 2.3 to 29.2 µg/m^3 and from 2.4 to 27.4 µg/m^3 in the spectator areas. The highest PM_{10} and $PM_{2.5}$ concentrations were measured at the liquid gas go-kart facility and at go-kart facilities with the maximum number of go-karts running simultaneously. The electric go-kart facility showed high PM_{10} concentrations but low $PM_{2.5}$ values. The highest particle number concentration was measured in the workplace of the facility using liquid gas go-karts (2.7×10^5 particles/cm^3), and the lowest concentration at both measurement points of the electrical go-kart facility (1.8×10^4 particles/cm^3). Metals such as copper, zinc, strontium, barium, aluminum, calcium, manganese, iron and nickel were found in nearly all samples with help of inductively coupled plasma mass spectrometry. The most abundant metal was iron, with concentrations up to 5.6 µg/m^3 (electric go-kart facility). Electron microscopic investigations showed high concentrations of soot in all samples, except for the samples of the electric go-kart facility. Additionally, agglomerates with iron and other metals were found in all samples. To summarize, electric go-karts, combined with a good ventilation system, seem to be more suitable for indoor use.

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1. Introduction

Go-karting is popular not only among professional riders but also among recreational riders. According to information provided by go-kart organizations children may drive go-karts alone after the age of 8 or if they are taller than 130 cm. A driver's license is not required for driving go-karts (Youngson and Baker, 1978). Therefore, go-karting is appealing for birthday parties, family celebrations or team building events.

The first go-kart was built approximately 60 years ago. It was a small, powerful, open top vehicle for single drivers (Kim and Wagner, 2010). Currently, go-karts can be found in all shapes and sizes (e.g., with two seats and for indoor and outdoor tracks). Safety equipment, such as helmets and racing suits, can be rented from go-kart companies. Go-karts are usually powered by a gasoline engine, but liquid gasoline engines and electric motors are also used.

The emissions of motor vehicles are an important source of air pollutants. Go-karts can be regarded as small versions of cars that could potentially generate comparable air pollutants (apart from gaseous pollutants), such as particulate matter from combustion, brake and tire debris (Grieshop et al., 2006; Miguel et al., 1998; Morawska et al., 2005).

There is a large body of evidence showing that exposure to motor vehicle-related particles is associated with significant risks to human health, such as chronic or acute pulmonary and cardiovascular diseases (Achilleos et al., 2017; Franco et al., 2013; HC, 2016; Lanki et al., 2015; Luo et al., 2015; Wyzga and Rohr, 2015). The harmful effects of particles depend on their size and chemical composition. Particles with an aerodynamic diameter less than 10 μm (PM_{10}) can penetrate into the lung. $PM_{2.5}$ particles (less than 2.5 μm in diameter) can reach the alveolar region, and ultrafine particles (< 100 nm) may pass into the bloodstream and cause systemic effects (Morawska et al., 2005). According to the World Health Organization (WHO), air quality guidelines values of 25 or 50 μg/m^3 were recommended for $PM_{2.5}$ and PM_{10} respectively on average over a 24-h period. For annual mean PM, guideline values of 10 μg/m^3 ($PM_{2.5}$) and 20 μg/m^3 (PM_{10}) were given. For the ultrafine particles (UFPs), which are measured as particle number concentrations, there is not a current recommendation (WHO, 2016).

The aim of this study was to estimate the exposure of go-karting employees and drivers to airborne particulate matter using various particle metrics, such us determining the concentrations and chemical compositions of airborne particulates, from eight indoor go-kart facilities. The measurement results of carbon monoxide, nitrogen oxides, volatile organic compounds and polycyclic aromatic hydrocarbons are described in a separate publication (Wolf et al., 2018).

2. Materials and methods

2.1. Study description and sample sites

The measurements were performed in eight indoor go-kart facilities. All go-kart tracks were located in Bavaria, Germany. Six of the facilities were equipped with go-karts using gasoline engines, one facility used electric motors and the other used liquid gas motors. Additionally, one go-kart facility was used for motorbike races. Each measurement was performed during opening hours, where up to 19 carts were on the track simultaneous. The measurement durations ranged between 5 and 8 h. The ventilation conditions are summarized in Table 1: go-kart pavilion No. 1 had no mechanical ventilation system only open-gate ventilation; go-kart pavilion Nos. 2 through 8 had mechanical ventilation systems, and no detailed information was provided regarding the ventilation. In most of the go-kart facilities the ventilation was operated all the time during the measurement. In go-kart facility No. 4 the ventilation was only switched on during the driving of the go-karts. Sampling and measurements were always performed at two different

Table 1
Overview of the go-kart facilities and the conditions during the measurements.

Go-kart facilities	Type of fuel	Max. number of go-karts on kart circuit during measurements	Ventilation system	Track length, m	Mean ± SD temperature track/spectator, °C	Mean ± SD relative humidity, track/spectator, %
No. 1	regular petrol	8	only open-gate ventilation	1000 (indoor plus outdoor)[a]	17.1 ± 0.7/17.5 ± 0.7	74.3 ± 1.8/70.1 ± 2.3
No. 2	benzene-free petrol	19	mechanical	610	16.8 ± 0.3/16.2 ± 0.3	44.5 ± 1.7/45.4 ± 1.9
No. 3	petrol/bioethanol	6	mechanical	–	19.6 ± 1.2/19.7 ± 1.1	59.9 ± 2.4/61.2 ± 1.6
No. 4	liquid gas	8	mechanical	350	22.2 ± 0.7/22.1 ± 0.9	30.8 ± 2.5/33.0 ± 2.9
No. 5	Aspen (green) petrol	12	mechanical	380 (indoor) plus 240 (outdoor)[a]	15.6 ± 0.8/15.6 ± 0.7	62.5 ± 7.6/57.9 ± 6.9
No. 6	Aral special fuel-benzene-free	8	mechanical	from 340 to 650	21.1 ± 0.9/20.9 ± 0.8	64.1 ± 5.5/69.9 ± 5.1
No. 7	electric	15	mechanical	550	19.8 ± 0.2/19.5 ± 0.3	41.2 ± 1.1/41.6 ± 1.2
No. 8	Aral special fuel-benzene-free	10 or 2 motorbike	mechanical	490	11.4 ± 0.7/n.m.	63.0 ± 1.3/n.m.

[a] under dry weather conditions both indoor and outdoor circuits were used as one track; n.m. - not measured.