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Abnormal Respiratory Symptoms of Workers and Sampling of Organic Vapors Using Solid-phase Microextraction Devices in a Golf Ball Manufacturing Factory

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ABSTRACT

The ink that is used in the mark printing, and the protective paints that are sprayed on golf balls as surface and primer layers are the main sources of volatile organic compounds (VOCs) in a golf ball manufacturing factory. In this investigation, workers' exposures to VOCs were evaluated using a needle trap sampler (NTS), which is a micro sampling device, and the results of an analysis using a gas chromatography mass spectrometer were compared to the samples that were collected in charcoal adsorption tubes with respect to VOC content. Ethyl acetate and n-butyl acetate are main compounds that are emitted in the painting and printing of golf ball. The highest worker time weighted average exposure concentration of n-butyl acetate was 16.92 ppm, and that for ethyl acetate was 19.69 ppm, as measured in a closed spray room. Painters' and printers' symptoms of respiratory tract abnormalities (RTA) were strongly correlated with their exposures to organic solvents as determined from the answers to a questionnaire survey on workers' RTA symptoms. An NTS can be used as an alternative to charcoal tubes for sampling organic solvents to which workers are exposed, based on the differences in the limiting VOC analysis concentrations of both sampling devices. Due to lighter weight and lower cost than the traditional charcoal tube, which has to be connected to a sampling pump, therefore, NTS should be promoted as a routine VOC monitoring device in the workplace.

Keywords: Volatile organic compounds, Micro sampler, Respiratory tract abnormality, Organic solvent, Golf ball

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1 INTRODUCTION

As the number of players of golf has increased, the printing of advertising logos on the surface of golf balls has become increasingly important for golf ball manufacturers. The ink that is used to transfer logo marks from the steel plates to semi-finished golf balls with a roughened surface, and the painting of transparent protective paints onto the balls as surface and primer layers are the main sources of emissions of volatile organic compounds (VOCs) in golf ball manufacturing (Kavas and Barton, 2016).

One of the health hazards of organic solvents is their tendency to cause respiratory tract injury (Rosenerg *et al.*, 2004). Organic solvents cause symptoms of respiratory tract abnormalities (RTA) in workers, which include coughing, phlegm, wheezing, dyspnea and shortness of breath (Hassan and Bayomy, 2015; Park *et al.*, 2006; Lee *et al.*, 1997; HPA, 2021). Workers who are involved in painting primer and logo printing on the surface of golf balls are exposed to the VOCs that are emitted from the inks and paints, including ethyl acetate (EAc), n-butyl acetate (BAc), 2-butoxyethanol (also known as ethylene glycol monobutyl ether, EGBE), toluene and xylenes; they are therefore likely to suffer from RTA.

Actually, the golf ball manufacturing process is catalogued to be an industrial emission source of organic solvents, so the Massachusetts Department of Environmental Protection has permitted an emission limit of ≤ 0.016 pounds (0.0073 kg) of VOCs per dozen finished golf balls to Callaway Golf Ball Operations, Inc. (MassDEP, 2022). However, few studies have investigated VOCs emitted from organic solvents in the golf ball manufacturing processes and their effects on workers' respiratory symptoms. This work investigates the correlations between VOC exposures and RTA symptoms in golf ball painting and printing workers. Workers' exposures to organic emission vapors were sampled by the active sampling method using adsorbent tubes (Method 1403 for EGBE, Method 1450 for esters, and Method 1500 for aromatic hydrocarbons) (NIOSH, 2003), and micro-sized needle trap samplers (NTS), which were passive samplers that were especially fabricated for the purpose. The questionnaire survey was used to identify printers' RTA symptoms, and their frequency of usage of respiratory personal protective equipment (PPE) to evaluate the effectiveness of on-site solvent emission control in the workplace.

2 METHODS

2.1 Extraction of VOCs Using Micro Samplers

In this work, NTS were used in passive sampling. Fig. 1 illustrates an NTS, which extracts VOCs through needles by diffusion (Lord *et al.*, 2010). A linear VOC concentration profile ($C(Z)$) is obtained along the diffusion path (Z), and the extraction of the VOC is characterized in term of the area (A) of opening and the length of the diffusion path. The total mass (n) of extracted VOC in an interval of sampling time (t) is estimated using Eq. (1) (Lord *et al.*, 2010):

$$n = D_m \frac{A}{Z} \int C(t) dt \tag{1}$$

where D_m is the diffusion coefficient of a VOC that is extracted using the NTS. The quantity (n) of the extracted VOC is assumed to be proportional to the mean sample concentration over a time interval ($C(t)$, which is also the time-weighted average (TWA) concentration) given constant values of D_m, A and Z.

The NTS, packed with adsorbent divinylbenzene (DVB) particles with 60–80 mesh diameters, has been successfully used to sample air emissions in both indoor and out-door working places (Cheng *et al.*, 2017; Cheng and Wu, 2019; Cheng *et al.*, 2020). Sulfonated DVB was synthesized using the sulfonation method that was developed by Huang *et al.* (2021), and packed into the NTS, which was thus able to adsorb effectively hydrophilic VOCs with high polarities. Matrixes of gaseous alcohol and aromatic hydrocarbons were thus extracted in an indoor workplace.

The uniformity of the packing phase in an NTS was determined using a procedure that has been described elsewhere (Cheng *et al.*, 2017; Cheng and Wu, 2019; Cheng *et al.*, 2020; Huang *et al.*, 2021). The desired air exhaustion rate through the NTS was obtained by drawing air through the

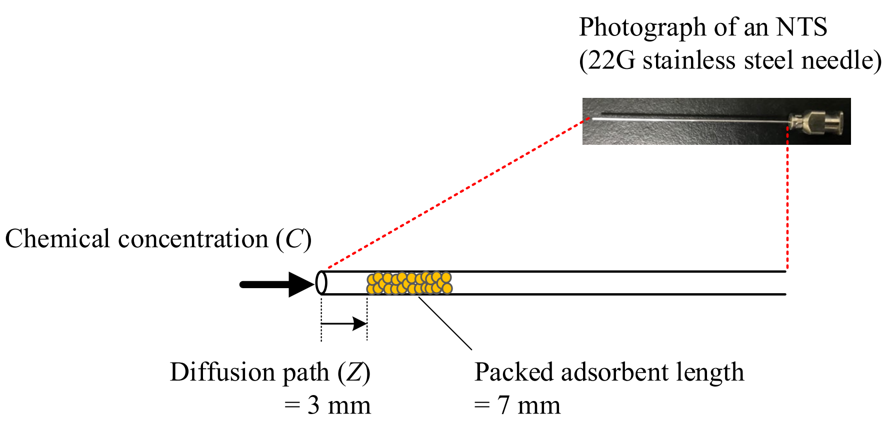

Fig. 1. Schematic configuration of needle trap samplers.

packing phase using an aspirating pump. When the relative standard deviation (RSD) of the air flow rates in triplicate tests did not exceed 5%, the packed materials inside the NTS were assumed to be uniformly immobilized. Based on Huang *et al.*'s (2021) and Helmig *et al.*'s (2022) study, gaseous standard samples of a mixture of hydrophilic ethanol and methyl ethyl ketone, and hydrophobic benzene, toluene, ethylbenzene and o-xylene (BTEX) (approximately 20 ppm for each compound) were prepared in a 500 mL Pyrex glass bulb, in which the NTS was placed for 1 h and 2 h to adsorb matrixes of VOCs. An NTS was placed for 1 h and 2 h to adsorb matrixes of VOCs in a bulb for testing the performance that the VOC adsorption mass of an NTS is indeed proportional to the sampling time. Additionally, when the RSD of the sampled mass in triplicate tests was less than 10%, the tested NTS was ready for use. The RSD of VOCs adsorption per five NTS also were less than 10%.

2.2 Chemicals, Materials and Instrumental Analysis

Stainless steel needles (22 G, length 7 cm and ID 0.41 mm) were purchased from a local company (Herling Co. Ltd., Pingtung, Taiwan) for use in preparing the NTS. DVB resin was purchased from Supelco (Bellefonte, PA, USA). Aspirating pumps, which were used to determine the NTS sampling flow rates, were manufactured by Kitagawa (AP-20, Kawasaki, Japan). All gases (Jing-De Gas Co., Ltd., Kaohsiung, Taiwan) that were used in chromatographic analyses were of ultra-high purity. All chemicals that were used in analysis and sulfonation synthesis were provided by Sigma-Aldrich (Munich, Germany).

Each NTS for extracting ethanol, methyl ethyl ketone and BTEX, was inserted into the injection port of a gas chromatography that was equipped with a flame ionization detector (GC-FID, 6890N, Agilent, Wilmington, DE, USA) to thermally desorb VOCs for analysis. The desorption time and temperature at the injection port were 30 s and 250°C, respectively. The temperature of the GC was increased from 50°C in increments of 15°C min^{-1} to 180°C, which was held for 2 min. The FID detector was heated to 300°C. The flow rate of the carrier gas, nitrogen, was 1.2 mL min^{-1}. The splitless operating mode was used for analysis. The calibration analyses of VOCs were implemented following a single procedure. Unknown chemical compounds, which were sampled using the NTS at the sites, were examined to determine the constituents using another gas chromatography-mass spectroscopy system (MS 5973, Agilent).

2.3 Sampling Plan, Questionnaire Development and Statistical Analysis

Workers' exposure to VOCs at the target golf ball manufacturing factory, which is located in the Pingtung Industrial Park, Pingtung County, southern Taiwan, was monitored. The factory is owned by an international world-class 480-employee OEM of golf balls, and two plants, Plants 1 and 2, currently have production lines, which has an annual output of 18 million dozen balls. Workers who perform the painting and printing procedures are continuously exposed to the organic vapors. Each NTS fixed on a plastic sheet, were worn in each workers' breathing zone, as shown in Fig. 2. The chemicals, adsorbed by NTS, were examined in a laboratory at Fooyin University. Each participating worker also wore another personal sampling device, comprising adsorbent tubes (Method 1403 for EGBE, Method 1450 for esters, and Method 1500 for aromatic hydrocarbons) (NIOSH, 2003), which was connected to a personal air pumps for active sampling (Fig. 2). The solvent vapors in the adsorbent tubes after sampling were analyzed by a contractor that was hired by the corporation to identify the compounds and their concentrations.

Based on the factors, including worker demographics, health status, job responsibilities, work environments and use of PPE, the American Thoracic Society's Adult Respiratory Tract Questionnaire was developed by Ferris (1978). A structured questionnaire, which was referred to Hung and Tsai's (2016) research on Taiwanese bakery workers by adopting originally the Ferris's questionnaire, was used for investigating the seniority of employees who are involved in painting and printing processes, their RTA symptoms, and the use of respiratory PPE. The questionnaire was developed in consultation with an occupational medical specialist. It was pre-tested on ten employees, and a reliability analysis was performed using the statistical software Statistical Product and Service Solutions (SPSS) (IBM Corp., 2021). The reliability coefficient, Cronbach's Alpha, was 0.837 > 0.7, indicating that this questionnaire had high reliability and dimensional consistency (Hee, 2014). Institutional Review Board (IRB) of Fooyin University reviewed and agreed with the implementation

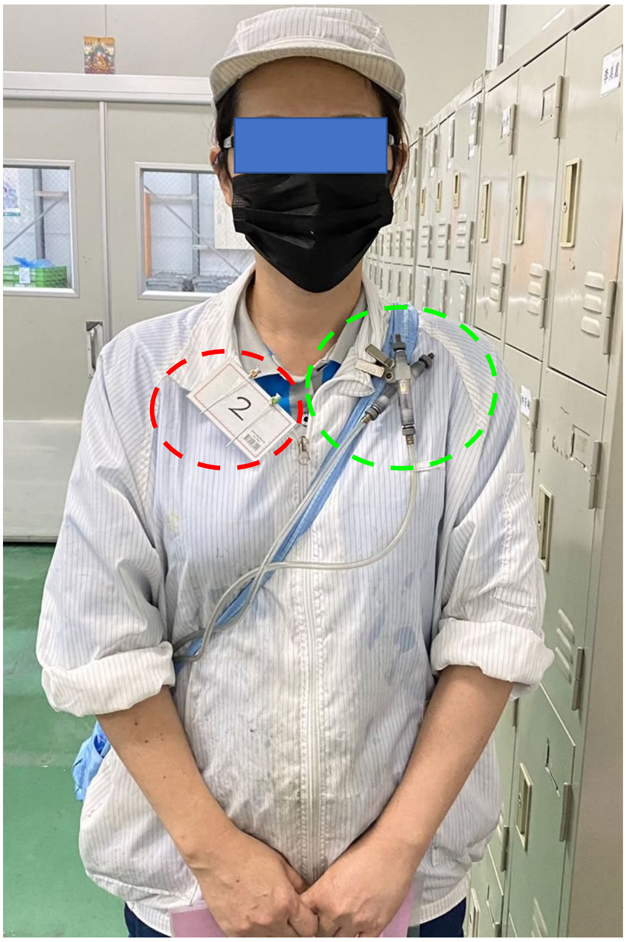

Fig. 2. Worker wore two types of samplers for monitoring the VOC exposure. Left red circle: needle trap samplers; right green circle: charcoal adsorption tubes.

of the questionnaire for this study in January, 2022. A one-way analysis of variance (ANOVA) was also performed using SPSS to determine differences between workers in Plants 1 and 2 inside the target factory for variances of RTA symptoms and relieves of RTA during the vacation, and use of respiratory PPE.

2.4 Calibration of VOC concentrations

For quantitative analysis, a calibration analysis for VOCs was performed. An experimental assistant inserted an NTS into a bulb, in which the concentration of VOC was set up as C_1. When the adsorption period the NTS was t_1, the gas chromatographic analysis area of this VOC sample was obtained as A_1. The concentration C_2 of the VOC at the site that was collected by the NTS is calculated as Eq. (2) (Cheng *et al.*, 2017; Cheng and Wu, 2019; Cheng *et al.*, 2020; Huang *et al.*, 2021).

$$C_2 = \left[\left(\frac{A_2}{A_1}\right) \times \frac{t_1}{t_2}\right] \times C_1 \qquad (2)$$

where A_2 is the VOC analysis area of the NTS over a sampling period of t_2 at the site. BAc was examined with an integral analysis of 6,349,926 by the GC, and the sampling time at the site was 360 min. The concentration of standard BAc prepared in the bulb is 10.05 ppm and the analysis area by the GC was 1,063,613 for an adsorption period of 60 min. Substituting the data into the Eq. (2), the concentration of ethylbenzene in the site was calculated as (6,349,926/1,063,613) × (60/360) × 10.05 = 10 ppm.

Table 1. Workers' VOC exposures during the painting and printing process of golf balls.

VOC components (CAS No.)	Concentrations (ppm)[a] Surface painting				Concentrations (ppm)[a] Primer painting/Mark printing			
	Plant 1		Plant 2		Plant 1		Plant 2	
	Charcoal (n =3)	NTS (n = 3)	Charcoal (n = 2)	NTS (n = 2)	Charcoal (n = 1)	NTS (n = 2)	Charcoal (n = 0)	NTS (n = 1)
Butyl acetate (123-86-4)	11.05 ± 5.42	11.73 ± 5.19	8.24 ± 0.67	8.38 ± 0.94	2.91	2.80 ± 0.56	na[b]	1.97
2-Butoxyethanol (111-76-2)	0.75 ± 0.35	0.90 ± 0.00	0.60 ± 0.01	nd	1.46	1.39 ± 0.30	na[b]	1.55
Ethyl acetate (141-78-6)	11.29 ± 8.40	11.98 ± 2.84	8.99 ± 2.29	9.53 ± 4.07	0.62	nd[c]	na[b]	nd[c]
Toluene (108-88-3)	na[b]	0.72 ± 0.40	na[b]	0.66 ± 0.40	na[b]	0.53 ± 0.24	na[b]	0.30
Xylenes (1330-20-7)	0.36 ± 0.00	0.46 ± 0.02	0.85 ± 0.00	0.74 ± 0.45	na[b]	nd–0.55	na[b]	0.37

[a] Concentrations are indicated as (median ± range).
[b] "na" indicates the compound was not examined.
[c] "nd" indicates concentrations of VOCs lower than the detection limits. NTS detective limits: 2-butoxyethanol = 0.25 ppm, butyl acetate = 0.29 ppm, ethyl acetate = 0.29 ppm, toluene = 0.06 ppm and xylenes = 0.06 ppm.

3 RESULTS AND DISCUSSIONS

3.1 Sampling and Analysis of VOCs in Workplaces

Six samples of charcoal tubes and eight NTS were taken in the Workplaces. Typically, the surfaces of golf balls are painted with oily paints; water-based paints are used for priming and for printing logo mark. According to Table 1, BAc and EAc are the main organic compounds that are emitted by surface painting in Plants 1 and 2. The highest concentration of BAc and EAc to which workers are exposed were 16.92 ppm and 19.69 ppm, respectively, and these values were measured in Plant 1. Since water-based paints were mainly used as primer painting and in printing marks, the concentrations of BAc and EAc were lower than those in the surface painting units. Notably, exposures top VOCs at the surface printing units in Plant 1 were significantly higher than those in Plant 2. The difference arises from the fact that higher concentrations of BAc and EAc accumulate in the closed spray room for the surface printing in Plant 1 than in the open spray area in Plant 2. Whatever a painter moves a box of golf balls into the spray room in Plant 1 for surface painting, he/she works inside the con-fined space for about 10 min. When the spray painting is completed, the worker must again enter the spray room to move the balls. In Plants 1 and 2, a single group of workers perform primer printing and mark printing together in each work shift. In Plant 1, workers' measured exposures to BAc (2.24–3.36 ppm), EGBE (1.09–1.69 ppm) and EAc (< 0.29–0.62 ppm) are higher than those measured in Plant 2 (1.97 ppm, 1.55 ppm and < 0.29 ppm). The VOC exposure concentrations may be related to the use of a closed spray room in the primer area in Plant 1.

Among five VOCs in Table 1, BAc and EAc are the most emitted compounds, which may cause headaches, dizziness and symptoms of RTA (NIOSH, 2007). Exposures to EGBE, toluene and xylenes are very limited. The permissible 8-hr time weighted average threshold limiting exposure concentration (TWA-TLV) of BAc is 150 ppm, and that of EAc is 400 ppm (NIOSH, 2007); these values are 16.7–18.3-fold the measured VOC concentrations in Table 1. The severity of the RTA symptoms of the workers and their exposures to low concentrations of VOCs were further evaluated using the aforementioned questionnaire survey.

The concentrations of VOCs to which workers were exposed that were measured using charcoals (NIOSH methods) and the NTS were very close to each other, as they differed by no more than 6%. Therefore, an NTS, which is a portable and reusable sampler that requires no solvents for extraction can be used as a micro-monitoring device instead of current NIOSH methods.

3.2 Characteristics of Painting and Printing Workers

According to Table 2, the average age of Plant 1 employees (excluding short-term employees who had been employed for less than 6 months) was 37.0 years old (between 27 and 48 years old), and the average age of Plant 2 employees was 31.9 years old (between 18 and 46 years old).

Table 2. General profile of the participating workers in the golf manufacturing plant.

Item of data	Plant 1	Plant 2
No. of volunteer participants	n = 44	n = 30
Age (years old)	Mean = 37.0, SD = 5.7	Mean = 31.9, SD = 7.4
	Max = 48, Min = 27	Max = 46, Min = 18
Gender	m = 27, f = 17	m = 13, f = 17
Seniority[a] (years)	0.6– < 1 = 10 (22.7%)	0.6– < 1 = 1 (3.3%)[b]
	1– < 2 = 7 (15.9%)	1–2 = 10 (33.3%)[b]
	2– < 5 = 11 (25%)	2–5 = 13 (43.3%)[b]
	≥ 5 = 16 (36.4%)	≥ 5 = 6 (20%)[b]
	Mean = 4.5, SD = 4.0	Mean = 3.7, SD = 3.3
	Max = 14.8, Min = 0.6	Max = 14.8, Min = 0.9

[a] Years of seniority are calculated based on Sep. 01, 2021.
[b] In Plant 2, workers with seniority exceeding 2 years were transferred from Plant 1, and still on the single job positions. Plant 2 workers with seniority lower than 2 years were newly hired.

Therefore, workers in Plant 2 were younger than those in Plant 1. Plant 2 began manufacturing golf balls two years ago. The painting and printing workers there with a seniority of more than two years had been transferred from similar positions in Plant 1, while those with less than two years of seniority had been newly hired. As many as 36.4% of Plant 1 painters and printers had been employed more than five years, and most (80%) of those in Plant 2 had been employed less than five years.

3.3 Analysis of Responses to Questionnaire Concerning VOC Exposure

According to data in Table 3 and the results of one-way ANOVA, over the past 12 months, the frequencies with which workers in the surface painting units in Plants 1 and 2 exhibited RTA symptoms differed significantly ($p = 0.008$), even during vacations ($p = 0.04$). The frequencies with which workers in the primer painting and mark printing units exhibited RTA symptoms differed very significantly between Plants 1 and 2 ($p = 0.008$), but not during vacations ($p = 0.13$).

According to Table 1, the exposure concentrations of VOCs in the surface painting units of Plant 1 were higher than in those of Plant 2; also those in the primer painting and mark printing units of Plant 1 were higher than in those of Plant 2. The results from the fact that all operational spaces in Plant 2 are open spaces, whereas the surface painting area of Plant 1 includes a closed spray room, exposing the workers inside to high concentrations of VOCs. Despite the fact the mark printing area in Plant 1 is an open space, and water-based ink is used in the primer and mark printing processes, the VOC exposure in the closed spray room in the primer area of Plant 1 are responsible for caused the workers' significant symptoms of RTA. The workers in the mark printing unit works in the open spaces in Plant 1. Therefore, the difference between the VOC exposures of workers in the primer painting and mark printing units between Plants 1 and 2 should be lower than between those in the surface paint units.

Based on the data in Table 4, the variance of the frequency of RTA symptoms that are exhibited by surface painting workers in Plants 1 and 2 on vacation is significant ($p = 0.04$), but for primer painting and marking printing workers, it is not ($p = 0.13$). Notably, of the employees in Plant 2 with more than two years of working seniority, who had been transferred from Plant 1, and 12 worked in the surface and primer painting units. These workers were transferred from the closed spray room in Plant 1, where VOC concentrations are higher, to Plant 2, where they are lower, so the transfer reduced their respiratory abnormalities.

According to the data in Table 5, no significant differences existed between Plants 1 and 2 with respect to the types of respiratory protective equipment used by workers in either the surface painting unit ($p = 0.18$) or the primer painting and mark printing units ($p = 0.20$). Table 5 reveals that most workers in Plants 1 and 2 wore flat activated carbon masks, regardless of whether they were exposed to high or low VOC concentrations. The painting and printing workers' resistance to wearing a gas-tight respirator also contributed to their RTA symptoms.

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Table 3. Results of workers' questionnaire survey on frequency of symptoms of respiratory tract abnormalities.

Symptoms	Surface painting, number of workers and percentage (%)									
	Plant 1 (n = 11)					Plant 2 (n = 9)				
	Never	Seldom	Sometimes	Usually	Always	Never	Seldom	Sometimes	Usually	Always
Nose and throat, dry or itchy	5 (45.5)	2 (18.2)	2 (18.2)	2 (18.2)	0 (0)	2 (22.2)	4 (44.4)	3 (33.3)	0 (0)	0 (0)
Nose and throat irritation or tingling	5 (45.5)	2 (18.2)	3 (27.3)	1 (9.1)	0 (0)	5 (55.6)	1 (11.1)	2 (22.2)	1 (11.1)	0 (0)
Runny nose, stuffy nose	0 (0)	6 (54.5)	3 (27.3)	2 (18.2)	1 (9.1)	1 (11.1)	2 (22.2)	5 (55.6)	0 (0)	1 (11.1)
Sneezing, coughing	2 (18.2)	3 (27.3)	4 (36.4)	1 (9.1)	1 (9.1)	2 (22.2)	2 (22.2)	3 (33.3)	2 (22.2)	0 (0)
Sputum, poor swallowing	4 (36.4)	2 (18.2)	2 (18.2)	2 (18.2)	1 (9.1)	4 (44.4)	2 (22.2)	1 (11.1)	2 (22.2)	0 (0)
Chest tightness, out of breath	3 (27.3)	2 (18.2)	2 (18.2)	4 (36.4)	0 (0)	4 (44.4)	0 (0)	3 (33.3)	2 (22.2)	0 (0)
Shortness of breath, wheezing	2 (18.2)	2 (18.2)	3 (27.3)	3 (27.3)	0 (0)	4 (44.4)	2 (22.2)	3 (33.3)	0 (0)	0 (0)
	Primer painting/Mark printing, number of workers and percentage (%)									
	Plant 1 (n = 33)					Plant 2 (n = 21)				
	Never	Seldom	Sometimes	Usually	Always	Never	Seldom	Sometimes	Usually	Always
Nose and throat, dry or itchy	10 (30.3)	8 (24.2)	8 (24.2)	7 (21.2)	0 (0)	11 (52.4)	4 (19.0)	6 (28.6)	0 (0)	0 (0)
Nose and throat irritation or tingling	18 (54.5)	5 (15.2)	8 (24.2)	2 (6.1)	0 (0)	14 (66.7)	2 (9.5)	5 (23.8)	0 (0)	0 (0)
Runny nose, stuffy nose	7 (21.2)	5 (15.2)	11 (33.3)	7 (21.2)	3 (9.1)	11 (52.4)	3 (14.3)	5 (23.8)	2 (9.5)	0 (0)
Sneezing, coughing	8 (24.2)	10 (30.3)	7 (21.2)	5 (15.2)	3 (9.1)	10 (47.6)	5 (23.8)	5 (23.8)	1 (4.8)	0 (0)
Sputum, poor swallowing	15 (45.5)	8 (24.2)	4 (12.1)	5 (15.2)	1 (3.0)	10 (47.6)	7 (33.3)	3 (14.3)	1 (4.8)	0 (0)
Chest tightness, out of breath	14 (42.4)	8 (24.2)	9 (27.3)	2 (15.2)	0 (0)	12 (57.1)	3 (14.3)	5 (23.8)	1 (4.8)	0 (0)
Shortness of breath, wheezing	21 (63.6)	5 (15.2)	5 (15.2)	0 (0)	0 (0)	11 (52.4)	5 (23.8)	4 (19.0)	1 (4.8)	0 (0)

The questionnaire was used to survey seven respiratory symptoms of workers from the past 12 months till September 2021. Frequency denotes: never < 1 day/week; seldom: 1 day/week; sometimes: 2–3 days/week; usually: 3–4 days/week; always: ≥ 5 days/week.

Table 4. Results of questionnaire survey on workers' relieve of respiratory symptoms on vacation.

Relieve of respiratory symptoms on vacation	Surface painting, number of workers and percentage (%)	
	Plant 1 (n = 11)	Plant 2 (n = 9)
Yes	3 (27.3)	0 (0)
No	8 (72.7)	9 (100)
	Primer painting/Mark printing, number of workers and percentage (%)	
	Plant 1 (n = 30)[a]	Plant 2 (n = 14)[a]
Yes	8 (26.7)	0 (0)
No	22 (73.3)	14 (100)

[a] Several painters and printers did not express opinions.

Table 5. Results of questionnaire survey on workers' use of respiratory protective equipment.

Respiratory protective equipment	Surface painting, number of workers and percentage (%)									
	Plant 1 (n = 11)					Plant 2 (n = 9)				
	Never	Seldom	Sometimes	Usually	Always	Never	Seldom	Sometimes	Usually	Always
Flat activated carbon mask	0 (0)	0 (0)	3 (27.3)	2 (18.2)	6 (54.5)	0 (0)	0 (0)	0 (0)	6 (66.7)	3 (33.3)
Half face-piece respirator with cartridges	2 (18.2)	1 (9.1)	5 (45.5)	1 (9.1)	2 (18.2)	4 (44.4)	2 (22.2)	1 (11.1)	1 (11.1)	1 (11.1)
	Primer painting/Mark printing, number of workers and percentage (%)									
	Plant 1 (n = 33)					Plant 2 (n = 21)				
	Never	Seldom	Sometimes	Usually	Always	Never	Seldom	Sometimes	Usually	Always
Flat activated carbon mask	1 (3.0)	2 (6.1)	10 (30.3)	5 (15.2)	15 (45.5)	0 (0)	0 (0)	0 (0)	10 (47.6)	11 (52.4)
Half face-piece respirator with cartridges	22 (66.7)	3 (9.1)	4 (12.1)	3 (9.1)	1 (3.0)	15 (71.4)	2 (9.5)	2 (9.5)	2 (9.5)	0 (0)

Frequency denotes: never < 1 day/week; seldom: 1 day/week; sometimes: 2–3 days/week; usually: 3–4 days/week; always: ≥ 5 days/week.

4 CONCLUSIONS

Painting in a closed spray room effectively isolates the emitted VOCs in a work-place. However, workers in a confined space are exposed to high concentrations of organic vapors and aerosols. Automatic painting or remote control operations can reduce the frequency with which laborers enter the spray room, and the severity of their abnormal respiratory symptoms that are caused by VOCs. To prevent occupational diseases, air-tight respiratory protective equipment must be worn by workers who enter a spray room where organic solvents are used.

In Taiwan, the exposure of workers to organic solvents must be monitored at least every six months, and a declaration made to the government. However, the number of VOCs that must be monitored has not been clearly specified by the government. Therefore, to keep down the monitoring budgets, employers typically do not monitor all emitted VOCs. Being of lighter weight (< 150 g) and lower cost (approximately USD 10) than the traditional charcoal tube with an air pump (approximately 1.2 kg and USD 800), an NTS can be used as a sampling device to determine the exposure of workers to organic solvents. According to the results of this evaluation, the workers' exposure concentrations of organic vapors which were examined respectively using the passive NTS and charcoal tubes connected to an active sampling pump were very close. Recently, passive micro detectors have been used to monitor indoor organic pollutants (Baysal *et al.*, 2021; Naccarato and Tagarelli, 2019). Therefore, the NTS should be also promoted to be an alternative sampling device of organic vapors and a routine VOC monitoring device in the workplace. However, in dusty workplaces (e.g., construction sites), fine particulate matters (PM) of in the air clog the adsorption layer inside an NTS, resulting in the sampler unusable (Cheng *et al.*, 2017). Therefore, fine PM in workplaces will reduce the effective sampling time of an NTS.

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DISCLAIMER

The authors declare no conflict of interest.

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