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RESEARCH ARTICLE

Chest circumference and birth weight are good predictors of lung function in preschool children from an e-waste recycling area

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Abstract The purpose of this study was to investigate the associations between birth weight, chest circumference, and lung function in preschool children from e-waste exposure area. A total of 206 preschool children from Guiyu (an e-waste recycling area) and Haojiang and Xiashan (the reference areas) in China were recruited and required to undergo physical examination, blood tests, and lung function tests during the study period. Birth outcome such as birth weight and birth height were obtained by questionnaire. Children living in the e-waste-exposed area have a lower birth weight, chest circumference, height, and lung function when compare to their peers from the reference areas (all p value <0.05). Both Spearman and partial correlation analyses showed that birth weight and chest circumference were positively correlated with lung function levels including forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1). After adjustment for the potential confounders in further linear regression analyses, birth weight, and chest circumference were positively associated with lung function levels, respectively. Taken together, birth weight and chest circumference may be good predictors for lung function levels in preschool children.

Keywords Chest circumference · Birth weight · Lung function · E-waste · Preschool children

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Introduction

Electronic waste (e-waste) has been recognized as the fastest-growing amount of waste in the world (Heacock et al. 2016; Zhang et al. 2012). The global quantity of e-waste doubled between 2009 and 2014, increased approximately 11% per year, and may increase to 65.4 million tonnes in 2017 (Breivik et al. 2014; Wang et al. 2016). It is estimated that approximately 80% of e-waste are illegally shipped from developed countries especially North America and Europe to developing countries such as China, India, Pakistan, Nigeria, and Ghana (Zhang et al. 2012). China processed about 70% e-waste produced worldwide (Wang et al. 2016; Zhang et al. 2012), and Guiyu (one of the largest e-waste destinations and recycling areas in the world) processed around 70% of the e-waste generated in China (Chen et al. 2011; Wu et al. 2010). E-waste in Guiyu has been recycled or disposed with informal methods such as open burning, roasting, acid leaching, dismantling, shredding, and dumping, which contribute to serious environmental pollution (air, dust, soil, water, and sediment) and pose a significant risk to human health (lung, kidney, brain, heart, and bone) (Song and Li 2014; Zeng et al. 2016a, b). Previous studies conducted in Guiyu have demonstrated that the concentration of $PM_{2.5}$ and the concentration of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), and copper (Cu) and persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), flame retardants (PBDEs), and dioxins/furans (PCDD/Fs) in $PM_{2.5}$ were higher than the most other sites in Asia (Deng and Wong 2006; Wong et al. 2007; Zeng et al. 2016a, b). Ambient particulate matter exposure has been associated with impaired health such as increased mortality and decreased lung function (Gauderman et al. 2004; Liu and Zhang 2009; Roy et al. 2012).

One of our previous studies showed that preschool children living in Guiyu have a higher prevalence of respiratory symptoms such as cough, dyspnea, phlegm and wheeze, and asthma when compared to peer from the reference area (Zeng et al. 2016b). Another study found that Guiyu primary school children (8–9 years old) have a lower lung function levels than those from the reference area (Zheng et al. 2013). Our recent study reported that lung function levels of preschool children (3–7 years old) in Guiyu were lower than the reference areas (Zeng et al. 2017). Ambient $PM_{2.5}$ concentration is associated with low birth weight (Fleischer et al. 2014; Pedersen et al. 2013). Chest circumference (CC) is recognized as an excellent indicator of birth weight (Rondo and Tomkins 1996; Thi et al. 2015), and birth weight (BW) is considered as a good predictor of lung function levels in adolescents and adults (Balte et al. 2016; Baumann et al. 2015; Saarenpaa et al. 2015). Our previous cross-sectional study found that BW and CC of preschool children were lower in Guiyu than those in the reference areas (Zeng et al. 2016b). Therefore, this raises kind of interesting question in terms of whether there is an association between BW, CC, and lung function levels in preschool children from e-waste-exposed area. The association between CC and lung function levels has been investigated by a few studies in older children, adolescent, and adults, but the results are inconsistent and inconclusive (Feng et al. 2012; Rosenthal et al. 1993; Whittaker et al. 2005). So far, the relationship between CC and lung function has not been investigated in younger children such as infants and preschool children. It is still needed to investigate whether BW and CC can predict lung function levels in preschool children.

Investigating individuals exposed to e-waste, such as preschool children in Guiyu, may help to identify the factors that contribute to birth weight, chest circumference, and lung function levels, and further confirm the association between birth weight, chest circumference, and lung function levels. In the current study, we recruited 206 preschool children aged 5 to 7 years from Guiyu (the e-waste-exposed area), and Haojiang and Xiashan (the reference areas). Birth outcomes such as birth weight and birth length were obtained from questionnaire. Physical growth and developmental parameters such as height, weight, and chest circumferences were measured during the epidemiological investigation. We performed spirometry to obtain lung function levels of forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1). This study aims to determine birth weight and chest circumference, and evaluate their effect on lung function levels.

Materials and methods

Study areas and population

The sampling site was located in Guiyu town in the southeastern coast of Guangdong Province in China. Haojiang (the first reference area) is located 31.6 km to the east of Guiyu and Xiashan (the second reference area) is located 5.8 km to the southeast of Guiyu (Fig. 1). There are similar demographic characteristics, lifestyles, and eating habits in these three areas. Haojiang and Xiashan were selected as the reference areas because they lack e-waste pollution. A total of 206 preschool children, 5–7 years old, were recruited from three kindergartens from Guiyu (n = 100), Xiashan (n = 54), and Haojiang (n = 52) during the period of November 2013 and December 2013. Participant received a general health questionnaire. All parents or guardians of the participants gave their written informed consent after receiving detailed explanations of the study and potential consequences prior to enrollment. This study protocol was approved by the Human Ethical Committee of Shantou University Medical College, China.

Physical growth and development test

Physical growth and developmental parameters such as height, weight, and chest circumferences were measured using a weight and height scale (TZ120; Yuyao Balance Instrument Factory, Yuyao, China) at the time of blood sample collection. Children were required to remove their shoes, take off their coat remaining light clothes, and maintain a certain standing posture prior to being measured. All measurements were carried out by a trained physician.

Spirometry

Spirometry was conducted with a portable spirometer (Jintan Medical Instrument Factory, Model DF-II, Jintan, Jiangsu, China) using standardized procedures following ATS criteria (Miller et al. 2005). Participants practiced the use of the mouthpiece with the spirometer until they felt comfortable under the guidance of the field physician. Results of three readings were recorded, and the highest reading of FVC and FEV_1 was used in the analysis.

Questionnaire

We collected information on potential routes of exposure to e-waste as well as general demographic and health parameters with a general questionnaire (Zeng et al. 2016b). The basic information collected by the questionnaire included age; gender; birth length; birth weight; family member daily smoking; socioeconomic status such as parental education levels and family income levels; eating habits such as eating daily

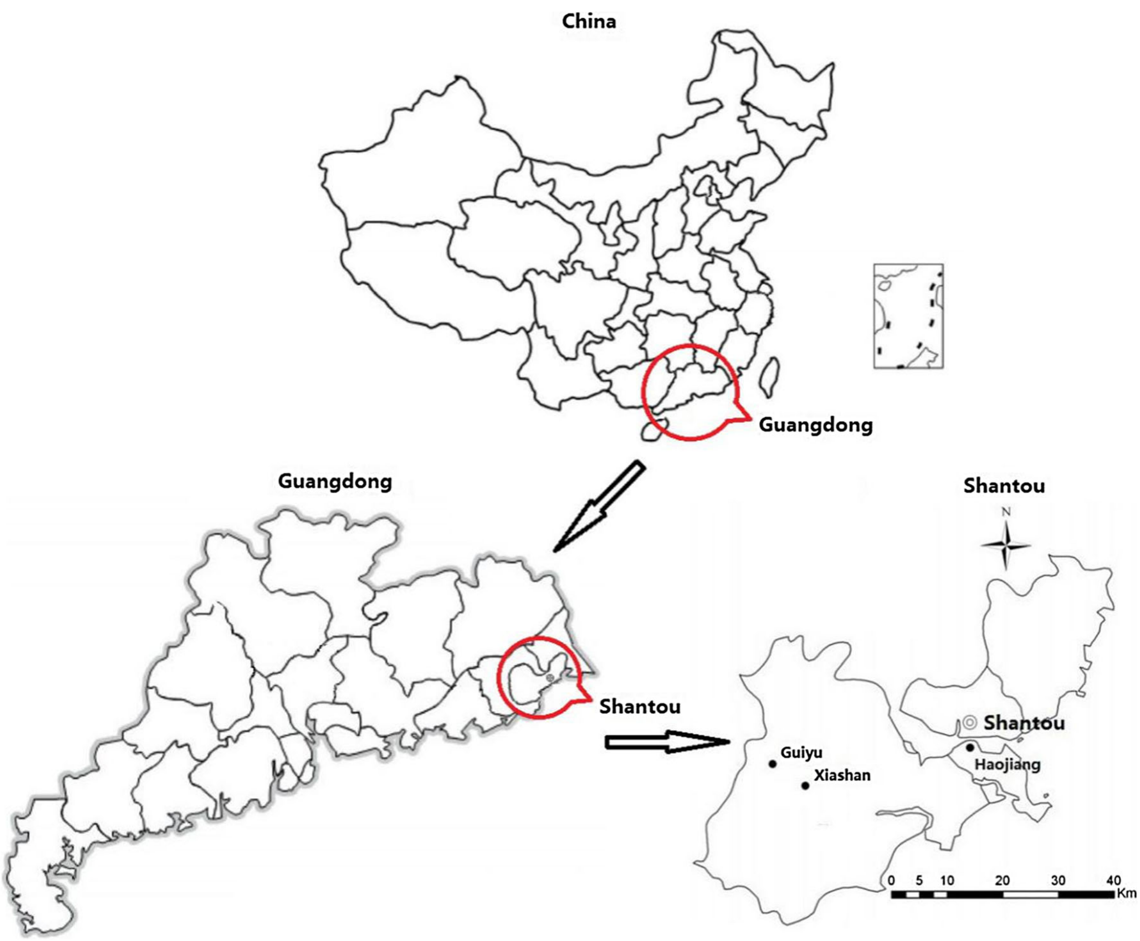

Fig. 1 The location of the sampling sites (Guiyu, Haojiang, and Xiashan)

products and eating canned food; behavior habits such as washing hands before eating, contact with e-waste, and outdoor daily playtime; and home location information such as distance from home to a road and home close to e-waste within 50 m. The parents or guardians of the children recruited in this study completed the questionnaire.

Sample collection and analyses

Peripheral blood samples were obtained from volunteers and collected in Pb-free tubes with EDTA as an anticoagulant by trained nurses. The blood sample was transported on ice to our laboratory and stored at minus 70 °C until analysis. Automatic hematology analyzer (Sysmex XT-1800i) was used for routine blood examination to obtain the levels of red and white blood cell counts and red blood cell distribution width (RDW).

Statistical methods

Data was expressed as median and interquartile range, or mean and standard deviation as appropriate according to its characteristics. The independent sample *t* test was used to test group differences of normally distributed data. The chi-squared test was used to test group differences of non-normally distributed data. Confounders such as age, gender, and height were included in the basic linear regression models when investigating the BW, CC, and lung function levels. In addition, the association between BW, CC, and lung function levels was analyzed by several linear regression models adjusted for the possible confounders. Family members daily smoking, socioeconomic status, eating habits, behavior habits, nutrition, and other potential confounders were included in the each final model when the *p* value of the confounder was lower than 0.05. Finally, the association between BW, CC, and lung function levels was assessed using multiple linear regression models. p values <0.05 were considered statistically significant. All analyses were performed in SPSS version 22.0 (IBM Corporation, NJ, USA).

Results

General characteristics of the study population

The general characteristics of the total of 206 preschool children in Guiyu (n = 106), Haojiang (n = 54), and

Xiashan ($n = 54$) are shown in Table 1. Ther was no significant difference in the mean age of preschool children between in the exposed area (5.53 ± 0.51 years, $n = 100$) and in the reference areas (5.54 ± 0.56 years, $n = 106$) ($p > 0.05$). Gender, weight, and body mass index (BMI) of children did not show significant differences (all $p > 0.05$). BW, CC, and height of children were lower in the exposed area compared to those in the reference areas ($p < 0.05$). Parents of children from the exposed area had a lower education, family income, while had a higher smoking prevalence ($p < 0.05$) (Table 1). The blood parameter information and lung function levels are shown in Table 2. Red and blood cell counts, and counts and the percentage of lymphocytes, showed no significant difference between the exposed and reference areas. However, the absolute value and percentage of RDW of children in the exposed area was higher than those in the reference areas. In addition, children from the exposed area have higher FVC and FEV_1 lung function levels compared to the reference areas ($p < 0.05$). However, no significant difference was found in the ratio of FVC to FEV_1 between the exposed group and the reference areas (Table 2).

Table 1 Demographic characteristics of the study population

Characteristics	Exposed area (n = 100)	Reference areas (n = 106)	p Value
Age (years)	5.53 ± 0.51	5.54 ± 0.56	0.881[a]
Gender, n (%)			0.283[b]
Boys	52 (52.0)	63 (59.4)	
Girls	48 (48.0)	43 (40.6)	
Chest circumference (cm)	52.63 (50.93–54.33)	53.42 (51.56–55.38)	0.037[c]
Birth weight (kg)	3.07 ± 0.49	3.25 ± 0.58	0.020[a]
Height (cm)	111.03 ± 5.95	112.56 ± 4.70	0.045[a]
Weight (kg)	19.30 ± 2.84	19.76 ± 2.46	0.412[a]
Body mass index (BMI; kg/m^2)	15.43 (14.86–16.33)	15.12 (14.35–16.24)	0.128[c]
Family member daily smoking, n (%)			0.000[b]
Non-smoking	31 (31.0)	58 (54.6)	
~2 cigarettes	14 (14.0)	11 (10.4)	
~10 cigarettes	23 (23.0)	16 (15.1)	
~20 cigarettes	26 (26.0)	14 (13.3)	
>20 cigarettes	6 (6.0)	7 (6.6)	
Parental education level, n (%)			<0.001[b]
Illiteracy	6 (6.0)	2 (1.9)	
Primary school	4 (4.0)	3 (2.8)	
Middle school	52 (52.0)	20 (18.9)	
Secondary school	25 (25.0)	22(20.7)	
High school	11 (11.0)	20 (18.9)	
College/university	2 (2.0)	39 (36.8)	
Family income level per month (¥), n (%)			0.001[b]
<1500	18 (18.0)	6 (5.7)	
1500–3000	24 (24.0)	14 (13.2)	
3000–4500	18 (18.0)	19 (17.9)	
4500–6000	18 (18.0)	18 (17.0)	
>6000	22 (22.0)	49 (46.2)	
Daily outdoor playtime, n (%)			0.280[b]
<0.5 h	18 (31.0)	15 (54.6)	
0.5~1 h	32 (14.0)	29 (10.4)	
1~2 h	33 (23.0)	43 (15.1)	
2~3 h	12 (26.0)	19 (13.3)	
>3 h	5 (6.0)	0 (6.6)	

Reference areas Haojiang and Xiashan; exposed area Guiyu

[a] Analysis by independent-sample t test

[b] Analysis by chi-squared test

[c] Analysis by Mann-Whitney U test

Table 2 Levels of physical parameters, blood parameters, and lung function parameters in preschool children from Guiyu, Haojiang, and Xiashan

Characteristics	Exposed area (n = 100)	Reference areas (n = 106)	p Value
Blood parameters			
Red blood cell count (0^{12}/L)	4.84 ± 0.35	4.91 ± 0.39	0.162[a]
White blood cell count (10^9/L)	8.42 ± 2.25	8.27 ± 2.00	0.620[a]
Lymphocyte count (10^9/L)	3.52 ± 1.07	3.45 ± 0.83	0.607[a]
Lymphocyte percentage (%)	42.24 (37.64–347.47)	43.44 (37.24–49.21)	0.171[b]
RDW-SD (fL)	36.75 (35.70–38.20)	36.10 (34.70–37.48)	<0.001[c]
RDW-CV (%)	12.79 (12.40–13.10)	12.40 (12.10–12.80)	0.002[b]
Lung function parameters			
FVC (L)	1.23 ± 0.24	1.33 ± 0.25	0.004[a]
FEV_1 (L)	1.16 ± 0.21	1.24 ± 0.23	0.005[a]
FEV_1/FVC	0.95 (0.91–0.97)	0.96 (0.92–0.98)	0.206[b]

Exposed area Guiyu; reference areas Haojiang and Xiashan. For continuous variables, average range is presented as mean values ± SD (normal distribution data) or median values with interquartile (non-normal distribution data

FVC forced vital capacity, *FEV_1* forced expiratory volume in 1 s, *FEV_1/FVC* the ratio of forced expiratory volume in 1 s to forced vital capacity

[a] Analysis by independent-sample t test

[b] Analysis by Mann-Whitney U test

[c] Analysis by chi-squared test

Chest circumference and related factors

There was a significant positive correlation between chest circumference and age (r = 0.191, p < 0.01), birth weight (r = 0.197, p < 0.01), height (r = 0.536, p < 0.01), weight (r = 0.839, p < 0.01), and BMI (r = 0.731, p < 0.01), respectively. To obtain factors associated with chest circumference, multivariate linear regression models were used to do further analysis. In the basic model, we found that age (β = 0.063, p > 0.05), gender as boys (β = 0.142, p < 0.001), height (β = 0.403, p < 0.001), and BMI (β = 0.636, p < 0.001) was positively associated with chest circumference. In the final models, daily outdoor playtime was negatively associated with chest circumference after adjusting for age, gender, height, and BMI (β = −0.115, p < 0.01). In addition, daily outdoor playtime was negatively associated with chest circumference after adjusting for age, gender, height, and BMI (β = −0.115, p < 0.01). Moreover, living in the e-waste-exposed area was negatively associated with chest circumference according to linear regression models (β = −0.132, p < 0.001) (Table 7).

Birth weight and related factors

According to the Spearman correlation analyses, we found that birth length (r = 0.255, p < 0.01), height (r = 0.179, p < 0.05), weight (r = 0.226, p < 0.01), and BMI (r = 0.169, p < 0.05) was positively correlated with birth weight (Table 3). Linear regression analyses were used to do further analysis to identify factors associated with birth weight. In the univariate models, we found that both parental education levels (β = 0.070, p < 0.05) and family income levels (β = 0.090, p < 0.01) were positively associated with birth weight of children. To further investigate whether living area post an adverse effect on birth weight, diverse linear regression models were used and analysis results demonstrated that living in the e-waste-exposed area was negatively associated with birth weight (β = −0.175, p < 0.05) (Table 7).

Table 3 Spearman correlation coefficients between chest circumference, lung function levels, and some investigated factors

	CC (cm)	Birth weight (kg)	Lung function levels (L)	
			FVC	FEV_1
CC (cm)				
Birth weight (kg)	0.197**			
FVC (L)	0.373**	0.209**		
FEV_1 (L)	0.344**	0.231*	0.961**	
Age (years)	0.191**		0.239**	0.196**
Birth length (cm)	−0.008	0.255**	0.227**	0.249**
Height (cm)	0.536**	0.179*	0.400**	0.359**
Weight (kg)	0.839**	0.226**	0.367**	0.343**
BMI (kg/m^2)	0.731**	0.169*	0.185**	0.187**

CC chest circumference, *FVC* forced vital capacity, *FEV_1* forced expiratory volume in 1 s, *FEV_1/FVC* the ratio of forced expiratory volume in 1 s to forced vital capacity, *BMI* body mass index

*p < 0.05, **p < 0.01

Lung function levels and related factors

Spearman correlation analyses were applied to study the correlation between birth length, birth weight, height, weight, BMI, chest circumference, and lung function levels. The analysis results demonstrated that birth length, birth weight, height, weight, BMI, and chest circumference were positively correlated with lung function levels FVC and FEV_1 (Table 3). Linear regression analyses were used to further investigate the factors contributing to FVC and FEV_1. Univariate linear regression models showed that gender, age, birth weight, height, BMI, chest circumference, family member daily smoking, and daily outdoor playtime were associated with lung function levels FVC and FEV_1 (Table 5). After adjusted for the confounders, family member daily smoking was negatively associated FVC ($\beta = -0.108$, $p < 0.05$) and FEV_1 ($\beta = -0.151$, $p < 0.05$), and daily outdoor playtime was negatively associated FVC ($\beta = -0.115$, $p < 0.05$) and FEV_1 ($\beta = -0.140$, $p < 0.05$), respectively (Table 5). Multiple linear regression analysis results showed that living in the e-waste-exposed area was negatively associated with FEV_1 ($\beta = -0.156$, $p < 0.05$) (Table 7).

Correlations between chest circumference and lung function levels

It is well known that height is a strong confounding factor for lung function levels. In addition to the correlation between age, birth weight, height, and BMI, and chest circumference in this study (Table 3), the partial correlation analysis was used to analyze correlation between chest circumference and lung function parameters FVC and FEV_1 by age (model A), birth weight (model B), height (model C), and BMI (model D) among preschool children, respectively (Table 4). All the four models demonstrate that chest circumference was positively correlated with lung function levels. In addition, we found that chest circumference was still positively correlated with FVC ($r = 0.182$, $p < 0.05$) and FEV_1 ($r = 0.155$, $p < 0.05$) when controlled for age, birth weight, height, and BMI in the final partial correlation analysis model (model E) (Table 4).

Table 4 Partial correlation analyses between chest circumference and lung function levels controlled by some correlated factors

	Lung function levels (*r*)	
	FVC	FEV_1
Chest circumference		
Model A	0.348***	0.325***
Model B	0.362***	0.326***
Model C	0.205**	0.193**
Model D	0.354***	0.310***
Model E	0.182*	0.155*
Birth weight		
Model F	0.234***	0.251***
Model G	0.149*	0.180*
Model H	0.180*	0.206**
Model I	0.144*	0.175*
Model J	0.153*	0.178*

Partial correlation analyses between chest circumference and lung function levels

FVC forced vital capacity; *FEV_1* forced expiratory volume in 1 s; *FEV_1/FVC* the ratio of forced expiratory volume in 1 s to forced vital capacity; *BMI* body mass index; *model A* control for age; *model B* control for birth weight; *model C* control for height; *model D* control for BMI; *model E* control for age, gender, birth weight, height, and BMI; *model F* control for age; *model G* control for height; *model H* control for BMI; *model I* control for chest circumference; *model J* control for age, gender, height, and BMI

$*p < 0.05$, $**p < 0.01$, $***p < 0.001$

Associations between chest circumference, birth weight, and lung function levels

Multiple linear regression analysis was performed to assess the association between chest circumference, birth weight, and lung function levels (Tables 5 and 6). We found that chest circumference was positively associated with FVC and FEV_1 both in the univariate model (FVC $\beta = 0.373$, $p < 0.001$; FEV_1 $\beta = 0.344$, $p < 0.001$), basic models (FVC $\beta = 0.149$, $p < 0.05$; FEV_1 $\beta = 0.140$, $p < 0.05$), and in the full models (FVC $\beta = 0.174$, $p < 0.05$; FEV_1 $\beta = 0.157$, $p < 0.05$) (Table 6). In addition, birth weight was positively associated with FVC and FEV_1 both in the univariate model (FVC $\beta = 0.209$, $p < 0.01$; FEV_1 $\beta = 0.231$, $p < 0.001$), basic models (FVC $\beta = 0.144$, $p < 0.05$; FEV_1 $\beta = 0.171$, $p < 0.05$), and in the full models (FVC $\beta = 0.146$, $p < 0.05$; FEV_1 $\beta = 0.176$, $p < 0.05$) (Table 6). Moreover, after adjustment for gender, age, height, and living area (Guiyu vs. Haojiang and Xiashan), there were still significant association between BW (FVC $\beta = 0.131$, $p < 0.05$; FEV_1 $\beta = 0.157$, $p < 0.05$), CC (FVC $\beta = 0.165$, $p < 0.05$; FEV_1 $\beta = 0.156$, $p < 0.05$), and lung function levels, respectively.

Discussion

In this study, we explored the levels of physical parameters such as birth weight, chest circumference, height, BMI, FVC, and FEV_1; evaluated the factors associated with the physical parameters and lung function levels including FVC and FEV_1; and estimated the association between birth weight, chest circumference, and lung function levels. We found that both birth weight, chest circumference, and lung function levels of children were lower from the e-waste-exposed area than the reference areas. Family member daily

Table 5 Multiple linear regression analysis of factors related to chest circumference and lung function levels in children

	Chest circumference			FEV_1		
	B^a	β^b	95% CI for B	B^a	β^b	95% CI for B
Univariate model						
Gender as boys	1.757	0.273	(0.888, 2.626)***	0.110	0.244	(0.050, 0.170)***
Age (years)	1.167	0.191	(0.326, 2.013)**	0.082	0.196	(0.025, 0.139)**
Birth weight (kg)	1.170	0.197	(0.312, 2.027)**	0.095	0.231	(0.037, 0.153)***
Height (cm)	0.318	0.536	(0.248, 0.389)***	0.015	0.359	(0.009, 0.020)***
BMI (kg/m^2)	1.422	0.731	(1.235, 1.608)***	0.025	0.187	(0.007, 0.044)**
Family member daily smoking	−0.218	−0.092	(−0.556, 0.120)	−0.031	−0.186	(−0.053, −0.008)**
Daily outdoor playtime	−0.362	−0.127	(−0.775, 0.051)#	−0.022	−0.103	(−0.053, 0.009)#
Parental education level	0.064	0.025	(−0.310, 0.438)	0.007	0.038	(−0.019, 0.033)
Family income level per month	0.442	0.175	(0.077, 0.807)*	0.023	0.129	(−0.002, 0.048)#
Full model						
Family member daily smoking	−0.196	−0.108	(−0.373, −0.019)*	−0.025	−0.151	(−0.046, −0.004)*
Daily outdoor playtime	−0.329	−0.115	(−0.558, −0.101)**	−0.030	−0.140	(−0.059, −0.001)*
Parental education level	0.052	0.020	(−0.153, 0.256)	0.002	0.010	(−0.023, 0.026)
Family income level per month	0.003	0.001	(−0.198, 0.205)	0.007	0.038	(−0.018, 0.031)

Full model adjusted by age, gender, height, and BMI

FEV_1 forced expiratory volume in 1 s, *BMI* body mass index, *CI* confidence interval

$0.05 < p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

[a] B unstandardized coefficients

[b] β standardized coefficients

smoking and daily outdoor playtime were negatively associated with chest circumference and lung function levels, respectively. Both chest circumference and birth weight were positively associated with FVC and FEV_1, and may be good predictors for lung function levels.

Previous studies demonstrated that age, gender, and height are important predictors for lung function (Brusselle 2009; Whittaker et al. 2005). However, there was no study investigated whether birth weight and chest circumference are good predictors for lung function in preschool children, particularly for peers from e-waste-exposed area. The main aim of the present study was to examine the association between BW and CC and lung function in preschool children from an e-waste-exposed area. To achieve this aim, age, gender, and height

Table 6 Association between chest circumference and lung function levels in children investigated by multiple linear regression analyses

	FVC			FEV_1		
	B^a	β^b	95% CI for B	B^a	β^b	95% CI for B
Chest circumference						
Univariate model	0.029	0.373	(0.019, 0.039)***	0.024	0.344	(0.015, 0.033)***
Basic model	0.012	0.149	(0.000, 0.023)#	0.010	0.140	(−0.001, 0.021)#
Full model	0.015	0.174	(0.001, 0.028)*	0.012	0.157	(−0.001, 0.024)*
Birth weight						
Univariate model	0.096	0.209	(0.031, 0.161)**	0.095	0.231	(0.037, 0.153)***
Basic model	0.065	0.144	(0.006, 0.124)*	0.069	0.171	(0.016, 0.123)*
Full model	0.063	0.146	(0.005, 0.122)*	0.069	0.176	(0.016, 0.122)*

Basic model for chest circumference adjusted for age, gender, height, and BMI. Full model for chest circumference adjusted for age, gender, height, BMI, RDW, family member daily smoking, and daily outdoor playtime. Basic model for birth weight adjusted for age, gender, height, and BMI. Full model for birth weight adjusted for age, gender, height, BMI, family member daily smoking, and daily outdoor playtime

FVC forced vital capacity, *FEV_1* forced expiratory volume in 1 s, *BMI* body mass index, *RDW* red blood cell distribution width

$0.05 < p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 7 Association between living area and chest circumference, birth weight, and lung function levels in preschool children

	Chest circumference			Birth weight			FEV_1		
	B^a	β^b	95% CI for B	B^a	β^b	95% CI for B	B^a	β^b	95% CI for B
Living in Guiyu									
Univariate model	−1.015	−0.117	(−1.799, −0.230)*	−0.186	−0.170	(−0.343, −0.030)*	−0.087	−0.194	(−0.147, −0.026)**
Basic model	−1.128	−0.130	(−1.759, −0.497)***	−0.182	−0.166	(−0.340, −0.024)*	−0.059	−0.134	(−0.116, −0.002)**
Full model	−1.151	−0.132	(−1.795, −0.508)***	−0.191	−0.175	(−0.354, −0.028)*	−0.071	−0.156	(−0.138, −0.004)*

Basic models for chest circumference and FEV_1 adjusted for age, gender, and height. Full models for chest circumference and FEV_1 adjusted for age, gender, height, family member daily smoking, parental education levels, and family income levels. Basic models for birth weight adjusted for gender. Full models for birth weight adjusted for gender, family member daily smoking, parental education levels, and family income levels

FEV_1 forced expiratory volume in 1 s, *BMI* body mass index

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

were firstly introduced into the basic models, followed by BMI, and then adjusted for family member smoking and outdoor playtime. The analysis showed that both BW and CC were good predictors for lung function levels.

Serving as an indicator of body size, BW and CC of preschool children were lower in the e-waste-exposed area than the reference areas. In further linear regression analyses, children living in the e-waste-exposed area have a high risk of decreased BW and CC. These findings may indicate that e-waste exposure have an adverse effect on the growth and development of children. In addition, FVC and FEV_1 of preschool children in the e-waste-exposed area were on average 7.5 and 6.5% lower than their peers in the reference areas, respectively. Overall, FVC and FEV_1 in boys were on average 9.2 and 9.1% greater than in girls. In the present study, children living in e-waste recycling area take a higher risk of lower lung function levels compared to their peers. Our previous studies demonstrated that e-waste post diverse adverse effects on human body, particularly children (Lin et al. 2017; Zeng et al. 2016a, b). It is imperative to continuously persuade the government and the public to take action to reduce e-waste pollution such as restricting imports of electronic waste, reducing e-waste pollution emissions, updating e-waste recycling instrument and equipment, and improving protection measures and awareness.

Studies on the relationship between BW, CC, and lung function have mostly been performed in adult populations, but there have been few studies in children (Baumann et al. 2015; Saarenpaa et al. 2015). To the best of our knowledge, the present study is the first that has explored the association between BW, CC, and lung function in a population of Chinese preschool children from e-waste exposure area. After adjustment for the potential confounders, BW and CC in preschool children were inversely associated with lung volumes including FVC and FEV_1. RDW is regarded a biomarker for with nutritional deficiency, and is associated with lung function (Grant et al. 2003). In this study, RDW of preschool children was higher in the e-waste-exposed area than in the reference areas. After additionally adjusting for RDW, there was still significant association between CC and lung function levels. These findings are consistent with the results of previous studies on the relationship between BW, CC, and lung function in adults.

Our previous study showed that children living in Guiyu (the e-waste exposure area) have a high risk of increased prevalence of respiratory symptoms when compared to their peers in the reference areas (Zeng et al. 2016b). This study demonstrated that children living in the e-waste-exposed area have a lower lung function levels when compared to those in the reference areas. Therefore, living area may be an important factor influencing the association between BW, CC, and lung function levels. The present study further strengthens the evidence linking living area and BW, CC, and lung function levels (Table 7). To eliminate the effect of living area on the association between BW, CC, and lung function levels, living area was included in the linear regression analyses as a confounder. The results of linear regression models showed that BW and CC were still positively associated with lung function (Table 7), which further confirms that BW and CC can be good predictors for lung function of preschool children.

A strength of this study was that preschool children from the e-waste-exposed and two reference areas were included. None of the subjects recruited in this study has no history of smoking. Former and current smoking is one of the most important confounding factors influencing lung function of adults. Preschool children obviate any influence of direct smoking. In addition, the effect of passive smoking, nutritional, and socioeconomic status is fully considered when performing the linear regression analyses in the present study. However, characteristic of this study, a cross-sectional study, prevents us taking a cause-and-effect relationship between BW, CC, and increased lung function. To corroborate causality between BW or CC and lung function, an individualized follow-up study is required in the future.

Conclusion

To summarize, we demonstrate that Guiyu children have a lower birth weight, chest circumference, and lung function levels compared to their peers in the reference areas. Our findings suggest that both birth weight and chest circumference are good predictors for lung function levels in preschool children. More indicators related to lung function should be measured to confirm our findings in the future study. A cohort study is requested to confirm causality and underlying mechanisms between birth weight, chest circumference, and lung function.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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