Polish J. of Environ. Stud. Vol. 20, No. 4 (2011), 1001-1007

Original Research

The Effects of Lead and Cadmium Pollution on Functional and Morphological Development of Middle School Students from Jastrzębie-Zdrój and Katowice

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Received: 14 October 2010
Accepted: 7 March 2011

Abstract

Based on the 1999-2006 annual reports of the Regional Environmental Monitoring System, differences in somatic and functional traits were evaluated among middle school students residing in cities with different levels of cadmium and lead air pollution. The sample consisted of 240 girls and 276 boys from Jastrzębie-Zdrój and Katowice aged 13 to 15 years. Place of residence and gender were independent variables, whereas dependent variables included morphological, muscular-motor, and cardiorespiratory components of health-related physical fitness (H-RF). Intergroup differences (between adolescents from Jastrzębie-Zdrój and Katowice) were assessed using Student's t-test for independent samples, separately for boys and girls. The results indicate that functional traits, in particular VO_2max and motor coordination, are more sensitive to negative effects of environmental factors than anthropometric characteristics.

Keywords: lead, cadmium, development, anthropometry, physical fitness, adolescents

Introduction

Both worldwide and Polish investigations concerning harmful effects of environmental pollution on the development and health of human populations have been conducted for a long time. Among them, a number of studies have been carried out on the effects of lead and cadmium concentrations in ambient air exceeding permissible levels. These heavy metals enter the human body in various forms. Negative influences of elevated blood lead levels on the development of intellectual [1, 2] and neuromuscular functions [3, 4], and agility [5] were demonstrated in schoolchildren. High levels of heavy metals in the blood have also been proven to damage both passive (bones) and active (muscles) components of the locomotor system. Lead accumulates predominantly in long bones; it acts by displacing calcium and forming lead phosphate deposits that reduce bone mass and strength. Thus, lead-exposed individuals suf-

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Table 1. Annual lead and cadmium levels (ng/m³) recorded at air quality monitoring stations close to schools in Katowice and Jastrzębie Zdrój.

Year	Katowice, Raciborska 39		Katowice, Obr. Westerplatte 51		Jastrzębie Zdrój, Harcerska 14b	
	Pb	Cd	Pb	Cd	Pb	Cd
1999	100	3.6	203	12.6	69	2.5
2000	101	3.4	204	9.3	79	2.4
2001	112	3.8	246	5.4	86	2.5
2002	74	3.0	205	4.9	54	1.8
2003	96	2.9	313	5.0	57	2.9
2004	68	2.7	221	5.2	49	1.8
2005	63	2.4	189	4.1	50	1.4
2006	86	2.7	296	5.6	53	1.6

fer from impairment of longitudinal bone development [6-8]. For example, a 2 cm decrement in the arm length in men and 2.5 cm in women can be observed at the lead blood level of 10 μg/dl. To a lesser extent, decrements in trunk length can also be observed, which can result in disproportions in the lengths of the extremities and the trunk [9]. Lead was also shown to negatively affect bone marrow and damage nervous tissue [10, 11]. Cadmium from dust falls, accumulated mainly in the lungs, causes lung function disturbances as well as neoplastic lesions, hypertension, and bone disease [12].

Polish investigations have most frequently focused on the harmful effects of chemical elements and compounds, released from the biosphere in the form of dust falls, on the somatic and motor development of children and adolescents [9, 11-16 and others]. Conclusions from research studies have emphasized that environmental pollution has more pronounced negative effects on functional (physical fitness and efficiency) than anthropometric traits [14-16].

The aim of our study was to evaluate some presumed differences in the somatic and functional development among middle school students from Katowice and Jastrzębie-Zdrój exposed to different lead (Pb) and cadmium (Cd) emissions in ambient air. Elevated levels of these elements may compromise immune resistance, thus increasing susceptibility to numerous diseases [17]. The areas of the mining sector and steel industries are particularly at risk of the impact of industrial dust emissions that enter the lungs with the inhaled air and then proceed into blood circulation. Lead and cadmium particles also fall onto and contaminate the soil entering the human body through food plants. When defining the research problem and aim, we were fully aware that none of the environmental factors operated independently, but that their effects were reinforced or attenuated by interactions with other factors [14, 16].

Material and Methods

The study was carried out in 2006 among 240 female and 276 male middle school students from Katowice and Jastrzębie-Zdrój, aged 13 to 15 years. Based on the 1999-2006 annual reports of the Regional Environmental Monitoring System, two schools from two Katowice districts with relatively high concentrations of airborne lead and cadmium particles (ng/m³) and one school in Jastrzębie-Zdrój, a city with much lower air pollution levels, were sampled (Table 1). Only students born and raised in Katowice or Jastrzębie-Zdrój, who had adjusted to the different air concentrations of heavy metals for a longer time, were recruited for the study.

The components of health-related fitness defined as morphological, muscular-motor, and cardiorespiratory fitness were selected as dependent variables [18-21].

The parameters of health-related fitness components were assessed through indirect observation, including anthropometric measurements of morphological parameters, and anthropomotor/physiological testing of muscular-motor and cardiorespiratory components (Table 2).

Place of residence and gender were independent variables used in statistical analysis. Dependent variables and their symbolic representations (digits and letters) are presented in Table 2. Differences in health-related fitness components of adolescents growing up at two locations differing as to the level of environmental pollution were assessed using Student's t-test for independent samples. Intergroup differences are represented as physical fitness profiles (mean and standard deviation) separately for boys and girls.

Results and Discussion

A comparison of the obtained results and with physical fitness norms for Upper Silesia adolescents reveals that the majority of analyzed parameters are within reference ranges typical of the age group (13-15 year olds) [22], which indicates proper selection of research material.

The data in Table 3 and Fig. 1 suggest that the differences between mean morphological component parameters (H-RF) for female inhabitants of Jastrzębie and Katowice did not reach the level of statistical significance, although a

Table 2. Diagnosed elements of health-related fitness components.

H-RF component	Variable symbol	Dependent variables	Unit	Test
Morphological	X_1	Body height	[cm]	–
	X_2	Body mass	[kg]	–
	X_3	BMI	[kg/m^2]	–
	X_4	Waist-to-hip ratio (WHR)	[i.u.]	–
	X_5	Fat mass	[%]	–
	X_6	Subscapular skinfold	[mm]	–
	X_7	Triceps skinfold	[mm]	–
	X_8	Abdominal skinfold	[mm]	–
	X_9	Total of three skinfolds	[mm]	–
	X_{10}	Flexibility	[cm]	Sit and reach
Muscular-motor	X_{11}	Absolute muscle strength	[m]	Medicine ball backward throw
	X_{12}	Static muscular power - forearm muscles	[kg]	Dynamometer handgrip test
	X_{13}	Explosive muscular power – lower extremities	[cm]	Standing long jump
	X_{14}	Maximum anaerobic power	[J]	MAP=m [kg]·g [m/s^2]·X_{13} [m]
	X_{15}	Muscle endurance – large muscle groups	[No. of repetitions]	Burpee Test
	X_{16}	Muscle endurance – shoulder girdle	[s]	Flexed arm hang
	X_{17}	Muscle endurance – abdominal muscles	[No. of repetitions/30 s]	Sit-up test
	X_{18}	Locomotor speed (agility)	[s]	Shuttle run 10×5 m
	X_{19}	Movement speed (frequency)	[s]	Plate tapping
	X_{20}	Static balance	[No. of repetitions]	Standing balance
	X_{21}	Dynamic balance	[m]	Walking balance
	X_{22}	Quick movement coordination	[No. of repetitions/20 s]	Side step test
Cardiorespiratory	X_{23}	Absolute aerobic capacity	[l/min]	Astrand-Ryhming test
	X_{24}	Relative aerobic capacity	[ml/kg/min]	Astrand-Ryhming test
	X_{25}	Absolute anaerobic capacity	[W]	Wingate test
	X_{26}	Relative anaerobic capacity	[W/kg]	Wingate test

slight advantage in body height and markedly thicker skinfolds were noted in the students from Jastrzębie-Zdrój. Ignasiak et al. [9, 15] noted a moderate effect of blood lead levels on the anthropometric parameters of girls and boys from the Legnica-Głogów Copper Basin.

Intergroup differences between the muscular-motor components did show statistical significance. The girls from Jastrzębie were superior to their Katowice counterparts on explosive muscular power (standing long jump), maximum anaerobic power (MAP), locomotor speed (shuttle run 10×5 m), and static and dynamic balance (standing balance, walking balance). The girls from Katowice did better only on the abdominal muscle endurance test (Table 4, Fig. 2). A negative correlation between static/explosive muscular power and blood lead level in 7-15-year-old girls was found by Ignasiak et al. [15] in their studies of the Legnica-Głogów Copper Basin children and adolescents.

Intergroup differences were also observed regarding cardiorespiratory parameters: girls from Katowice were diagnosed with lower absolute and relative aerobic (VO_2 max) and anaerobic capacity; but intergroup differences in anaerobic capacity were not statistically significant (Table 4, Fig. 2).

Among the studied morphological parameters of physical fitness, only spinal flexibility turned out to be significantly better in the male adolescents from Jastrzębie-Zdrój, who also displayed slightly higher body weight and height; however, the differences between the Jastrzębie and Katowice means were within the standard error (Table 3,

Table 3. Intergroup differences in somatic parameters of female and male adolescents aged 13-15 years (variable: place of residence).

Dependent variables	Gender	$\bar{x}$	SD	$\bar{x}$	SD	Student's test	p
		Jastrzębie		Katowice			
Body height [cm]	F	162.39	7.64	160.88	6.59	1.64	0.10
	M	169.15	8.83	168.67	9.99	0.43	0.67
Body mass [kg]	F	53.03	9.21	52.10	9.43	0.77	0.44
	M	58.14	12.74	57.25	11.24	0.62	0.53
BMI [kg/m²]	F	20.02	2.54	20.05	2.91	-0.09	0.93
	M	20.18	3.25	19.98	2.75	0.55	0.59
Waist-to-hip ratio (WHR) [i.u.]	F	0.74	0.08	0.73	0.01	0.35	0.73
	M	0.80	0.07	0.80	0.05	0.56	0.58
Fat mass [%]	F	21.62	4.88	22.22	4.18	-1.03	0.31
	M	10.55	4.92	10.35	4.14	0.36	0.72
Subscapular skinfold [mm]	F	14.35	6.87	10.50	4.20	1.11	0.27
	M	10.32	4.84	10.53	5.11	-0.23	0.82
Triceps skinfold [mm]	F	16.12	6.22	10.50	2.38	1.79	0.08
	M	11.30	4.59	9.88	3.44	1.71	0.09
Abdominal skinfold [mm]	F	16.34	6.52	10.00	2.16	1.93	0.06
	M	13.03	7.38	11.16	7.57	1.32	0.19
Total of three skinfolds [mm]	F	46.81	18.56	31.00	6.38	1.69	0.09
	M	34.33	15.82	31.56	15.42	0.91	0.36
Flexibility [cm]	F	23.77	6.70	23.51	7.13	0.28	0.78
	M	20.29	7.18	18.03	6.84	2.47	**0.01**

Statistically significant differences ($p<0.05$) are marked in bold.

Fig. 3). Mleczko and Ambroży [23] obtained similar results in their research on girls and boys living on the outskirts of Kraków.

A comparison of the muscular-motor component of physical fitness in male adolescents yielded slightly heterogeneous results. Static power of forearm muscles was greater in the students from Katowice, whereas those from Jastrzębie were superior on coordination tests (Table 4, Fig. 4). Other parameters of the component were not significantly different between the groups. Markedly higher absolute and relative aerobic capacity as well as a significantly better capacity for absolute anaerobic metabolism ($p<0.05$) was shown by the boys from Jastrzębie (Table 4, Fig. 4).

Overall, it should be emphasized that more differences were found between the groups of girls from Katowice and Jastrzębie, which comes as a surprise since the female gender has been considered less sensitive to environmental factors [21, 23, 24].

Our results confirm previous observations that the level of airborne gases and industrial dusts does not cause significant differences in somatic traits of girls and boys [14, 15, 23]. However, it should be noted that a disadvantage in body height and mass of 1-3 cm and 1 or 2 kg, respectively, was only seen in children and adolescents inhabiting areas where the blood lead level exceeded 12 μg/dl [24]. Regrettably, no such data have been available regarding the entire adolescent population of Upper Silesia. Notwithstanding, data from Table 1 indicates that the atmospheric levels of lead and cadmium were systematically declining in 1999-2006 due to industrial restructuring in Silesia. This might also have affected our results.

Considerable intergroup differences were observed regarding motor coordination. A lower level of motor coordination was noted in the Katowice students, which can be explained by the higher air cadmium and lead pollution levels in Katowice than in Jastrzębie-Zdrój. This can be supported by the fact that somatic build parameters regarded as important determinants of functional development were not significantly different between boys and girls. This confirms the hypothesis of Ignasiak et al. [11] and Domaradzki and Ignasiak [12] that above-average concentrations of airborne cadmium impair the regulatory function of the nervous system and motor coordination, whereas lead accumulation causes microdamage to nervous tissue. Similar

Table 4. Intergroup differences in muscular-motor and cardiorespiratory parameters of female and male adolescents aged 13-15 years (variable: place of residence).

Dependent variables	Gender	$\bar{x}$ Jastrzębie	SD Jastrzębie	$\bar{x}$ Katowice	SD Katowice	Student's test	p
Absolute muscle strength [m]	F	6.96	1.45	7.14	1.28	-1.01	0.32
	M	10.00	2.17	9.87	2.51	0.42	0.68
Static muscular power – forearm muscles [kg]	F	29.77	5.72	29.60	4.92	0.24	0.81
	M	35.68	8.21	40.48	10.16	-4.04	**0.00**
Explosive muscular power – lower extremities [cm]	F	169.33	21.85	162.78	18.65	2.45	**0.01**
	M	195.40	21.62	194.19	27.08	0.38	0.70
MAP [J]	F	877.31	181.28	824.45	166.35	2.30	**0.02**
	M	1112.01	271.66	1123.29	293.93	-0.31	0.76
Muscle endurance – large muscle groups [No of repetitions]	F	25.96	13.34	28.99	15.21	-1.57	0.12
	M	37.29	15.56	38.71	17.46	-0.66	0.51
Muscle endurance – shoulder girdle [s]	F	10.73	8.93	9.14	7.42	1.29	0.20
	M	19.17	11.85	16.73	10.92	1.59	0.11
Muscle endurance – abdominal muscles [No. of repetitions/30 s]	F	21.65	3.90	22.91	3.92	-2.44	**0.02**
	M	25.13	3.62	24.60	3.74	1.11	0.27
Locomotor speed (agility) [s]	F	22.10	1.75	22.95	1.67	-3.73	**0.00**
	M	20.61	1.66	20.87	1.51	-1.26	0.21
Movement speed (frequency) [s]	F	11.36	1.23	11.53	1.29	-1.01	0.32
	M	11.20	1.38	11.33	1.34	-0.74	0.46
Static balance [No. of repetitions]	F	9.12	4.21	12.94	4.50	-6.43	**0.00**
	M	9.20	4.15	12.16	4.31	-5.25	**0.00**
Dynamic balance [m]	F	32.10	8.04	28.02	7.64	3.94	**0.00**
	M	33.99	7.36	28.10	8.39	5.77	**0.00**
Quick movement coordination [No. of repetitions/20 s]	F	39.73	5.19	39.58	5.89	0.21	0.83
	M	41.25	6.19	39.15	6.16	2.61	**0.01**
Absolute aerobic capacity [l/min]	F	2.22	0.74	1.78	0.32	3.61	**0.00**
	M	2.54	0.55	2.21	0.43	-3.76	**0.00**
Relative aerobic capacity [ml/kg/min]	F	42.99	14.91	35.61	10.40	2.61	**0.01**
	M	45.95	10.62	38.36	8.89	-4.43	**0.00**
Absolute anaerobic capacity [W]	F	416.00	64.22	385.74	96.46	0.99	0.32
	M	593.89	135.17	541.54	135.48	1.99	**0.05**

Statistically significant differences ($p<0.05$) are marked in bold.

conclusions were reached by Munoz et al. [5], who demonstrated negative effects of above-average blood lead concentrations on the agility of 7-9-year-old children. Agility depends on neuromuscular coordination, which becomes impaired by high amounts of lead in the blood [3, 26]. High levels of exposure to heavy metals may result in acute or chronic damage to the nervous system [2, 16].

Mleczko and Ambroży [23], as well as Mleczko et al. [27], demonstrated lower aerobic capacity in individuals growing up in more polluted areas of suburban Kraków; the disadvantage was more pronounced in their female subjects. Our results suggest similar intensity of the phenomenon in girls and boys. Mleczko et al. [27] believe this is caused by the harmful effect of high lead contents in dust falls on respiratory chain processes. Mleczko and Ambroży [23] claim that 'more apparent effects of aerobic mechanisms on some skills are strongly suggestive of a negative impact of environmental pollution'.

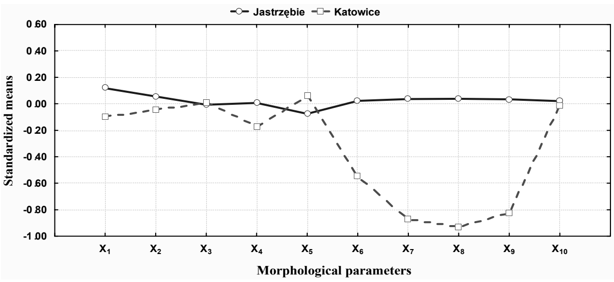

Fig. 1. Mean values of morphological component parameters in 13-15-year-old girls growing up in cities with different levels of environmental pollution.

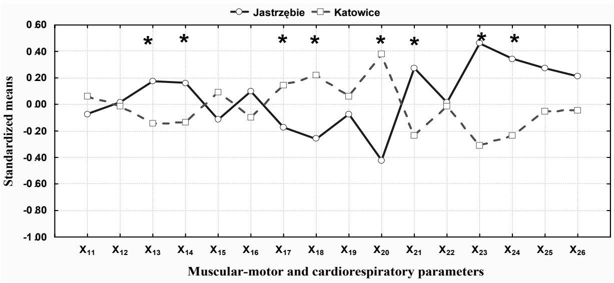

Fig. 2. Mean values of muscular-motor and cardiorespiratory components in 13-15-year-old girls growing up in cities with different levels of environmental pollution.

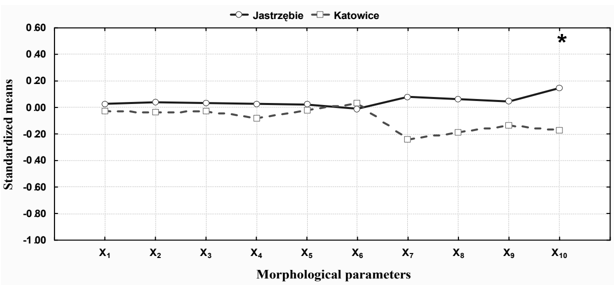

Fig. 3. Mean values of morphological component parameters in 13-15-year-old boys growing up in cities with different levels of environmental pollution.

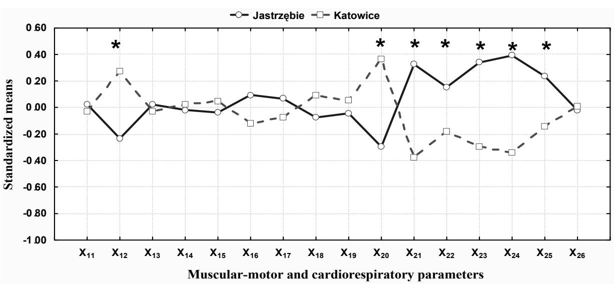

Fig. 4. Mean values of muscular-motor and cardiorespiratory components in 13-15-year-old boys growing up in cities with different levels of environmental pollution.
Statistically significant differences ($p < 0.05$) in Figs. 1-4 are marked with an asterisk.

Larger differences in functional development of female adolescents as compared with their male counterparts found in our study were also observed by Ignasiak et al. [15], Mleczko and Ambroży [23], Stinson [24], and Mleczko [28]. Mynarski et al. [22] emphasize that the lesser influence of environmental factors on the physical fitness of boys might result from higher levels of physical activity as compared with their female peers, regardless of subject age or social stratifications. Thus, physical activity is an important stimulus for development, and a means of disease prevention and health promotion.

The above data seem to confirm the hypothesis of Mleczko and Ambroży [23], as well as Domaradzki and Ignasiak [12], that functional traits, particularly maximal oxygen consumption and motor coordination, are more sensitive indicators of the negative impact of environmental pollution on the development of children and adolescents than anthropometric characteristics.

The assumption that no environmental factor affects the human body independently but always in conjunction with others points to some interesting observations. The different levels of air pollution in the growing up environment of the studied groups of adolescents were certainly only one of the reasons for the noted differences in the subjects' functional development. Other reasons could be place of residence and social and material conditions of their families, including cultural patterns of behavior such as active leisure pursuits. Physical activity can be a stimulus compensating for the negative impact of other factors, also environmental pollution of growing up environments. The complexity of this issue is also accounted for in conclusions.

Conclusions

1. Functional traits of 13-15 year-old adolescents are more susceptible to negative effects of lead and cadmium levels in ambient air than their somatic characteristics.
2. Slightly more noticeable differences can be observed in the muscular-motor component of physical fitness in female adolescents, which could have been an effect of a lower level of participation in physical activity in girls than in boys.
3. The obtained results seem to confirm a hypothesis that functional traits, and particularly coordination skills and aerobic capacity, are more reliable and accurate indicators of adverse effects associated with environmental pollution than anthropometric parameters.
4. Our results also indirectly suggest the importance of optimal amounts of physical activity, which may offset or compensate for the negative effects of environmental pollutants.

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