THE EFFECTS OF PHYSICAL EFFORT ON PULMONARY UPTAKE OF SELECTED ORGANIC COMPOUND VAPOURS

MAREK JAKUBOWSKI, DSc, PhD and HANNA WIECZOREK, PhD

Department of Metabolism of Toxic Substances, Nofer's Institute of Occupational Medicine, Lodz, Poland

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Abstract. Influence of workload on uptake of following solvents: tetrachloroethylene, trichloroethylene, m-xylene, n-butanol and acetone has been investigated in experimental conditions. Six volunteers were exposed by inhalation at rest and under workload: 25W, 50W and 75W under solvents vapours concentrations approximating the Polish MAKs. Retention of investigated compounds was relatively stable at different workloads applied in the course of experiments. Pulmonary ventilation ranged from 6.5 to 11 l/min at rest. Rectilinear correlation between intake and uptake with increased workload may be assumed for all compounds investigated, independently of their physicochemical properties as well as their toxicokinetics in the organism. According to literature and own data the 25W, 75W and 150W workload resulted in respectively, a twofold, a threefold and a fourfold increase of pulmonary uptake in comparison with pulmonary uptake at rest.

I. INTRODUCTION

There are numerous data on the mechanism of pulmonary absorption of organic compound vapours and factors affecting the absorption efficiency (2—16, 18, 19). Physical effort, increasing pulmonary ventilation and minute heart volume, also involve increased pulmonary uptake of organic compounds vapours. A quantitative evaluation of the relationship between the magnitude of physical effort and uptake is particularly valuable under industrial exposure, especially with only external exposure being measured. This issue was investigated by Droz and Fernandez (12), who developed a model allowing researchers to verify MAKs depending on the physical effort involved and physicochemical properties of the compound as well as its toxicokinetics in the organism.

Address reprint requests to M. Jakubowski, Department of Metabolism of Toxic Substances, Nofer's Institute of Occupational Medicine, 8 Teresy Street, 90-950 Lodz, P.O.Box 199, Poland

According to this model, for compounds exhibiting high blood: air partition coefficient (λ_B), and considerable metabolism in the organism, MAKs must be verified with varying physical effort. On the other hand, physical effort would not significantly affect the compounds of low λ_B and low metabolism in the organism. Åstrand (2—9), investigating the effects of physical effort, demonstrated a rectilinear correlation between intake and uptake for compounds of relatively high blood: air partition coefficients. For compounds of low λ_B values (about 10), the obtained data seemed to confirm the inferences of Droz and Fernandez (12) on the lower significance of the effects of physical effort on their pulmonary uptake (Fig. 1).

It must be considered, however, that Åstrand's investigations involved

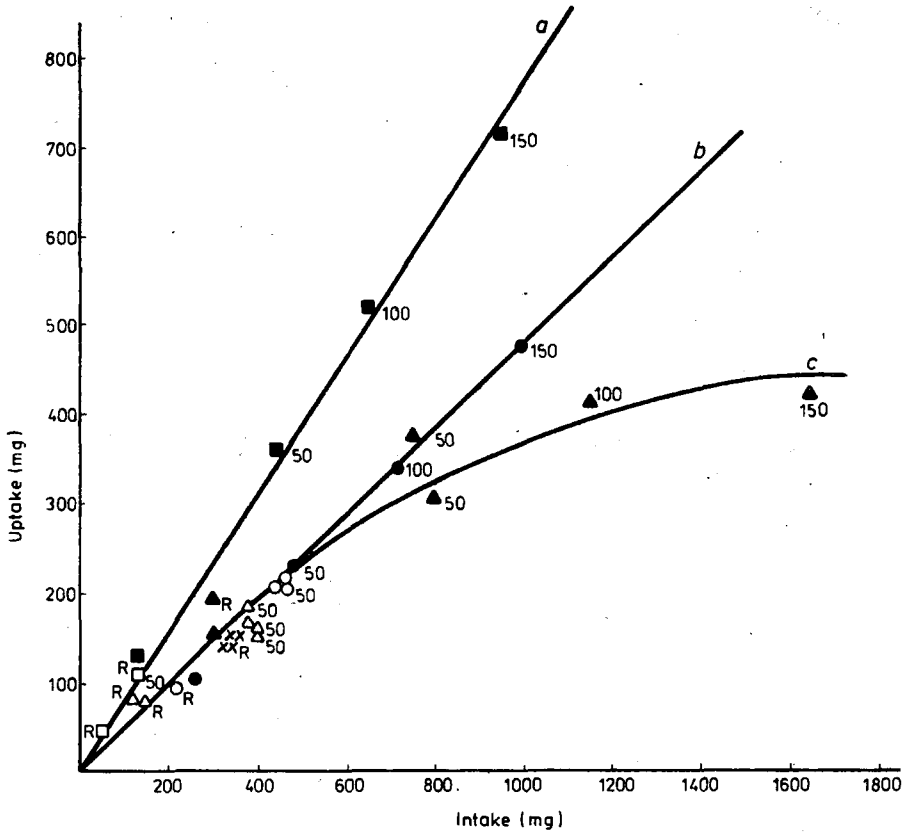

Fig. 1. The relationship between intake and uptake of solvents vapours in the lungs under differentiated workload (0, 50, 100, 150 Watt). R — rest; *a* — styrene, Åstrand (4), concentrations in air: □ — 212 mg/m³; ■ — 636 mg/m³; *b* — acetone, Wigeaus (19), concentrations in air: ○ — 712 mg/m³; ● — 737 mg/m³; x — 1349 mg/m³; *c* — trichloroethylene, Åstrand (8), concentrations in air: △ — 540 mg/m³; ▲ — 1080 mg/m³.

very high concentrations in air, so that partial pressures in alveolar air and capillary blood were equalized even under a relatively low workload. Therefore, it was interesting to find out whether a rectilinear relationship between intake and uptake at varying physical efforts applies also to compounds of low λ_B values at airborne concentrations approximating the hygienic standards mandatory in Poland. This issue is very important in practice due to the possibility of evaluating actual exposure from the known concentrations of organic compound vapours in air and known nature of work.

II. MATERIAL AND METHOD

II.1. Solvents investigated

Trichloroethylene, tetrachloroethylene, m-xylene, acetone, and n-butanol were used. They differ considerably in physicochemical properties (λ_B values of: approx. 9, 15, 30, 245 and 1200, respectively) (17) and in the efficiency of metabolism in the organism.

II.2. Subjects

The subjects of this study were six healthy male volunteers aged 25-40. The experiments were preceded by a detailed medical examination of the volunteers and anamnesis excluded their use at the time of any drugs or alcohol.

II.3. Exposure

Desired concentrations of solvents vapours were generated in an exposure chamber, the diagram of which is presented in Fig. 2. The generation of vapours was based on continuous injection of liquid compounds

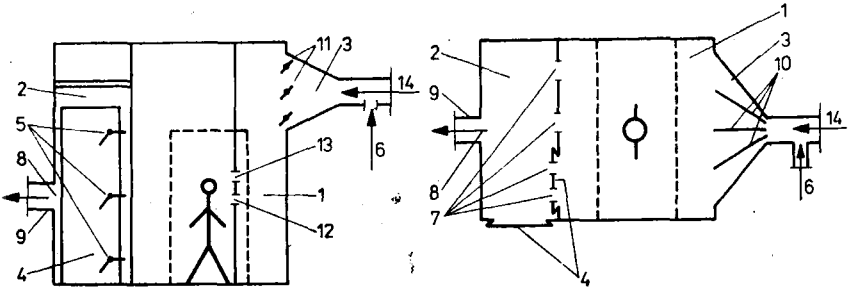

Fig. 2. The diagram of exposure chamber for inhalatory experiments: 1 — exposure chamber, 2 — flood-gate, 3 — mixing chamber, 4 — gas-tight door, 5 — locks, 6 — air inflow, 7 — air outflow from exposure chamber, 8 — air outflow from flood-gate, 9 — air-shaft, 10 — barriers, 11 — jalousies, 12 — sampling part, 13 — fresh air inflow to the mask, 14 — injection point for substances under investigation.

(laboratory grade) into the pressed air stream, at a controlled speed. The vapours were mixed with air in order to obtain desired concentrations approximating the Polish MAK values.

The volunteers were exposed to the solvents vapours outside the chamber breathing the air from the chamber through a face mask at rest or during exercise on a bicycle ergometer at a workload of 25, 50 and 75 Watt. Each experiment lasted 2 hours. Three days' break separated consecutive experiments.

II.4. Analytical methods

The solvent concentrations in the inhaled air were monitored continuously before the mask within infrared analyser (Beckman Acculab 6 equipped with Foxboro gas cuvette with the path length adjustable up to 20 m) and graphically recorded. Analytical parameters used during experiments are presented in Table 1.

TABLE 1. Analytical Parameters of the Methods Used for Monitoring of Investigated Compounds Concentrations in the Air

Compound	Gas chromatography					Infrared spectrophotometry	
	Stationary phase	Column			Carrier gas flow (cm^3/min)	λ (cm^{-1})	Path length (m)
		Length (m)	I.d. (mm)	Temp. (°C)			
Tetrachloroethylene	15% SE-30 on Varaport 30	3	3.5	130	40	9.15	5.25
Trichloroethylene	15% SE-30 on Varaport 30	3	3.5	110	30	9.45	5.25
m-Xylene	15% SE-30 on Varaport 30	3	3.5	130	40	7.65	5.25
n-Butanol	Porapak Q	0.75	2	160	35	10.50	5.25
Acetone	Porapak Q	0.75	2	110	30	11.95	5.25

The solvent concentrations in the exhaled air were measured using gas chromatography. Samples were collected through the sampling tube placed behind outlet valve of the mask and injected into the gas chromatograph by means of the sampling loop (volume 2 cm^3) every two minutes. Gas chromatograph (Giede, G.D.R.) equipped with flame ionisation detector was used. Analytical parameters applied during experiments are presented in Table 1.

Throughout the entire exposure the volume of expired air was measured using a resistance-free respirometer (Vol — Flow) at 10 min intervals.

TABLE 2. Influence of the Workload on Uptake of Investigated Solvents in the Lungs. Mean Values and Standard Deviations are Given

Compounds (Polish MAC value)	Work-load (W)	N	Concentration in the inspired air (mg/m³)	Retention	Pulmonary ventilation (m³/h)	Intake (mg/h)	Uptake (mg/h)
Tetrachloroethylene (60 mg/m³)	Rest	5	61±2.1	0.46±0.09	0.52±0.10	32± 2.6	14± 2.6
	25	5	63±3.1	0.52±0.11	0.93±0.37	58±20.0	29±10.0
	50	5	61±2.0	0.46±0.05	1.45±0.13	89±10.0	39± 5.8
	75	5	59±3.6	0.42±0.09	1.70±0.10	100± 3.8	42± 7.5
Trichloroethylene (50 mg/m³)	Rest	5	48±3.0	0.40±0.05	0.65±0.07	30±1.8	12±1.1
	25	5	49±1.3	0.40±0.05	1.30±0.14	64±5.1	25±2.9
	50	5	49±1.6	0.42±0.06	1.53±0.13	75±7.1	31±2.8
	75	5	48±1.9	0.41±0.06	1.87±0.14	91±7.3	37±4.8
m-Xylene (100 mg/m³)	Rest	5	97±11	0.48±0.04	0.59±0.07	58±11	28±5.7
	25	5	97±14	0.50±0.10	1.15±0.09	112±14	57±18
	50	5	101±16	0.50±0.06	1.39±0.06	141±28	71±21
	75	5	93±8.8	0.53±0.05	1.67±0.11	153±17	80±14
n-Butanol (200 mg/m³)	Rest	5	194±4.4	0.61±0.03	0.49±0.08	97±18	59±8.7
	25	5	194±7.9	0.60±0.01	1.15±0.18	222±37	135±24
	50	5	190±3.1	0.61±0.04	1.49±0.16	284±34	174±26
	75	5	190±8.2	0.60±0.03	1.76±0.20	332±34	199±28
Acetone (200 mg/m³)	Rest	5	197±4.0	0.43±0.04	0.39±0.13	78±24	34±11
	25	5	194±3.7	0.42±0.06	1.08±0.11	210±20	88±14
	50	5	195±4.9	0.40±0.10	1.51±0.15	293±32	118±34
	75	5	197±1.8	0.44±0.02	1.85±0.21	364±45	159±22

The retention (R) of solvents vapours in the lungs was calculated as the ratio of concentration decrease to the concentration of solvent in the inspired air:

$$R = \frac{C_{inh} - C_{exh}}{C_{inh}} \quad (1)$$

III. RESULTS AND DISCUSSION

Data on the solvent concentrations in inhaled air, retention, pulmonary ventilation, intake and uptake of solvents in the lungs are presented in Table 2. Retention of investigated solvents in the lungs was relatively stable at different workloads applied during the course of experiments. Pulmonary ventilation at rest ranged from 6.5 to 11 l/min. These results are concordant with those obtained by other authors (5, 13, 14).

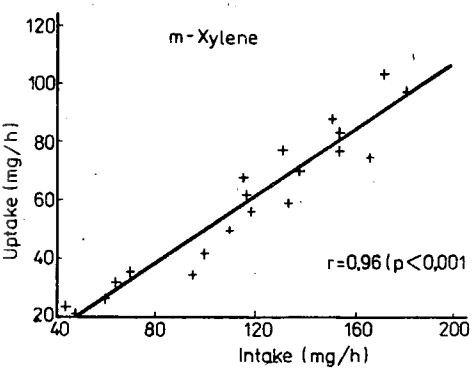

Fig. 3. The relationship between m-xylene vapours (intake and uptake in the lungs under differentiated workload (0, 25, 50 and 75 Watt) and the concentration in air of approx. 100 mg/m³.

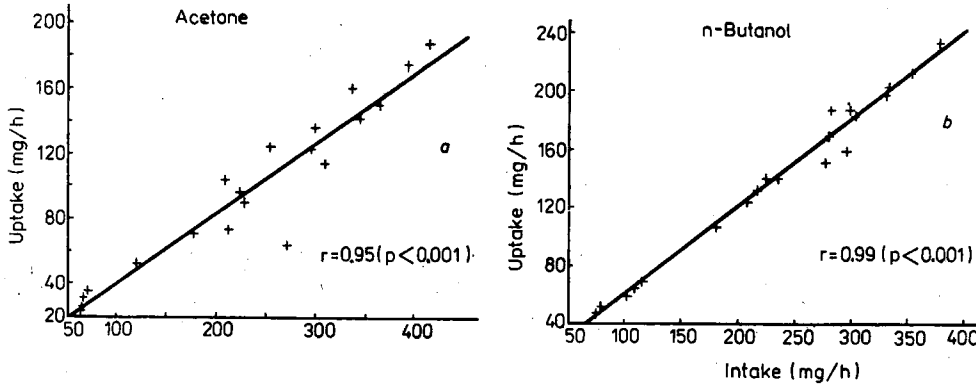

Fig. 4. The relationship between acetone (*a*) and n-butanol (*b*) vapours intake and uptake in the lungs under differentiated workload (0, 25, 50 and 75 Watt) and the concentration in air of approx. 200 mg/m³.

For compounds of low blood: air partition coefficient literature data pointed to missing rectilinear dependence of uptake upon intake with increased workload under inhalation exposure (6, 8, 15). However, Fig. 1 implies a range of airborne concentrations at which the relationship concerned will be linear even for those compounds. The results obtained in our investigations demonstrate a rectilinear correlation between intake and uptake under concentrations approximating Polish MAKs and workload typical of chemical industry plants, whatever the physicochemical properties of the test compounds (Fig. 3, 4, 5), although the cal-

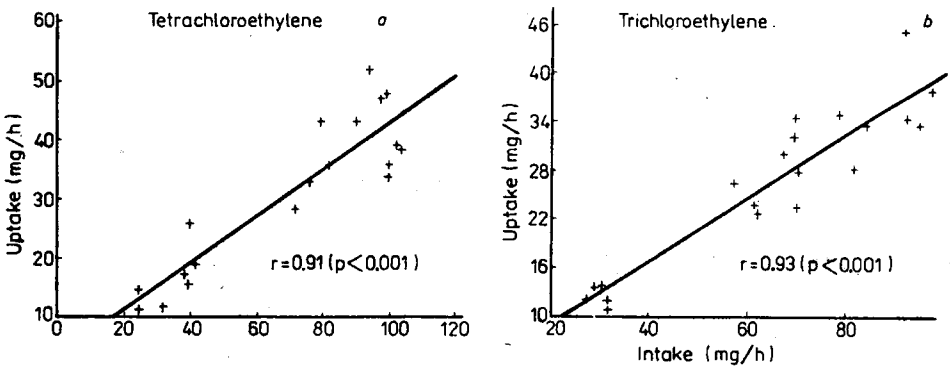

Fig. 5. The relationship between tetrachloroethylene (*a*) and trichloroethylene (*b*) vapours intake and uptake in the lungs under differentiated workload (0, 25, 50 and 75 Watt) and the concentrations in air of approx. 60 mg/m³ (*a*) and 50 mg/m³ (*b*), respectively.

culated correlation coefficients are slightly lower for tetrachloroethylene (r = 0,91) or trichloroethylene (r = 0,93), as compared to acetone (r = 0,95), n-butanol (r = 0,99) or xylene (r = 0,96).

Table 3, apart from our own data on pulmonary uptake at an increasing physical effort, includes available literature data. The data were largely convergent with those obtained in our investigations, especially when considering methodological differences and different reactions to subjects' effort. The 25W effort resulted in a twofold, whereas the 75W in a threefold pulmonary uptake.

The effects of physical effort on pulmonary uptake of organic solvents vapours should be also considered when establishing biological limit values with MAK values in air underlying the interpretation of results. For instance, in WHO publications (20), the 8-hr xylene exposure, at 200 mg/m³ concentration, is assumed to comply with average urinary concentration of methylhippuric acid, i.e. 1,4 g/l. As interpretation of results is based on experimental data obtained at rest it seems that two-

TABLE 3. Influence of the Workload on Uptake of Organic Solvents Vapours in the Lungs

Compound, reference (conc. mg/m³ exposure, time)	Rest (mg)	Uptake (mg) and quotients of amounts taken up at rest (q)									
		25W		50W		75W		100W		150W	
		mg	q	mg	q	mg	q	mg	q	mg	q
1. **Acetone**											
a) **Wigeaus (1981)**											
(740; 30 min)	112			225	2.0						
b) own data,											
(200; 120 min)	68	176	2.6	236	3.5	318	4.7				
2. **n-Butanol**											
a) Åstrand (1976)											
(300; 30 min)	43			80	1.9			130	3.0	190	4.4
b) own data,											
(200; 120 min)	118	270	2.3	348	2.9	398	3.4				
3. **Methylene chloride**											
Åstrand (1975a)											
(870, 30 min)	123			253	2.1						
4. **Xylenes**											
a) Åstrand (1978)											
(435; 30 min)	80			216	2.7			300	3.8	390	4.9
(870; 30 min)	164			400	2.4						
b) own data,											
(100; 120 min)	56	114	2.0	142	2.5	160	2.9				
5. **Toluene**											
a) Veulemans (1978)											
(190; 100 min)	62	145	2.4	220	3.6						
b) Åstrand (1972)											
(376; 30 min)	57			158	2.8	190	3.3				
(752; 30 min)	100			327	3.3	407	4.1				
6. **Trichloroethylene**											
a) Åstrand (1976a)											
(540; 30 min)	80			166	2.1						
b) own data,											
(50; 120 min)	24	50	2.1	62	2.6	74	3.1				
7. **Tetrachloroethylene**											
a) own data,											
(60; 120 min)	28	58	2.1	78	2.8	84	3.0				
8. **Styrene**											
a) Åstrand (1974)											
(640; 30 min)	126			350	2.8			504	4.0	720	5.7
Mean±RSD		2.25 ±10%		2.67 ±19%		3.50 ±18%		3.45 ±15%		4.88 ±12%	

fold urinary concentration of methylhippuric acid applies better to light work (25W).

IV. CONCLUSIONS

The data obtained demonstrate that under exposure to organic solvents vapours at concentrations approximating the Polish MAKs (Table 2) and under industrial workload (up to 75W on average) (1, 10),

a linear correlation between intake and uptake may be assumed not only for compounds of higher (above 30) blood: air partition coefficients, but also for those compounds for which those values are low (approx. 10).

The above data are essential for proper evaluation of exposure when only external exposure is measured, as well as for establishing biological limit values with MAKs in air as a basis.

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