THE ENVIRONMENTAL HEALTH OF CHILDREN: PRIORITIES IN EUROPE

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Abstract

Objectives: To evaluate existing research on the environmental health of children and provide a prioritised list of risk factors and policy recommendations for action, the Policy Interpretation Network on Children's Health and Environment (PINCHE) was set up within EU FP5 (QLK4-2002-02395). The project focused on air pollutants, carcinogens, neurotoxicants and noise. PINCHE was a multidisciplinary and multinational network of representatives from science, industry, NGOs, and consumer and patient organisations in Europe. Materials and methods: A literature search was performed using the Pubmed, Embase and Toxline databases. The quality of the gathered articles was assessed and their information and relevance was interpreted within a systematic framework. Information related to exposure, epidemiology, and toxicology was analysed separately and then a risk evaluation of particular environmental factors was made. Socioeconomic factors were specifically taken into account. The results were compiled, and considering the present regulatory situation, policy recommendations for action were made. Finally, the risk factors and policy recommendations were prioritised through a process of discussion between all the partners. Results and conclusions: PINCHE concluded that outdoor air pollutants (especially traffic-related), environmental tobacco smoke, allergens, and mercury were high priorities with an urgent need for action. Brominated flame retardants, lead, PCBs and dioxins, ionising and solar radiation, and some noise sources were classified as being of medium priority. Some toxins were given low priority, based on few exposed children, relatively mild health effects or an improving situation due to past policy measures. We recognise the shortcomings of such a prioritisation and, though some measures are more urgent than others, emphasise that ideally all policy measures should be carried out without delay for all toxins. This priority list must be continuously revised, the precautionary principle should be central to all decisions, and the focus should be on safe exposure levels for children.

Key words:
Child, Environmental health, Air pollution, Carcinogens, Neurotoxicology, Noise

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INTRODUCTION

The Policy Interpretation Network on Children’s Health and Environment (PINCHE) was a network set up and funded by the EU for three years (from January 2003 until January 2006) to focus on the relationship between children’s health and the environment. The main objective of PINCHE was to provide policy recommendations with the aim of protecting children’s health and environment based on published scientific research. The backbone of PINCHE was the recognition that children are more susceptible to some environmental factors than adults, while most legislation is based on data for adults.

PINCHE’s aim was to identify the environmental risk factors to which children are susceptible or have an increased risk of exposure and where special protective or preventive measures are required. It focused on the interpretation of existing scientific results to provide decision-makers, environmental health professionals and other stakeholders with information relevant for developing policy. In the final step, PINCHE prioritised recommendations for action to improve the environment of children in Europe [1].

The project focused on four themes:

Among indoor and outdoor air pollutants, nitrogen dioxide, particulate matter, ozone, environmental tobacco smoke, moulds and allergens were considered. Under the neurotoxicity theme, PINCHE focused on polychlorinated biphenyls (PCBs), dioxins, brominated flame retardants, pesticides, volatile organic compounds and heavy metals. In the third theme on noise, both involuntary and voluntary noise exposure in children’s settings was studied.

The carcinogenic compounds analysed were those listed on the IARC 1 and IARC 2a lists (Table 1) [2]. Some compounds on these lists were excluded because exposure was not considered relevant for children in Europe. The chosen themes were among those also prioritised by the European Commission and the World Health Organization [3,4]. Environmental stressors that are possibly hazardous to children’s health but were not studied in PINCHE include electromagnetic fields, endocrine disruptors (other than PCBs, dioxins, pesticides and brominated flame retardants), phthalates and carcinogens classified by IARC as group 2b carcinogens.

PINCHE was a multidisciplinary and multinational network of representatives from science, industry, NGOs, and consumer and patient organisations in Europe. Researchers such as epidemiologists and toxicologists, public health administrators, policy scientists and representatives of patient organisations, industry and non-governmental organisations within environment and health were partners in PINCHE. The broad spectrum of stakeholders that contributed to the project is a strength of PINCHE because its results are based on discussions from a variety of perspectives, even though it proved to be difficult to reach consensus on all recommendations. The scientific results were evaluated in seven workpackages: on exposure assessment; epidemiology; toxicology; risk and health impact assessment; socioeconomic factors; science–policy interface; and the workpackage final analysis. At the end of the project, workpackage 7 was the forum that created the priority list of the policy recommendations discussed in the present article. PINCHE reviews of health risks due

Table 1. Classification of carcinogenic agents as defined by the International Agency of Research on Cancer (IARC)

<table>
<thead>
<tr>
<th>Group</th>
<th>Classification</th>
<th>Definition (simplified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carcinogenic agent</td>
<td>There is sufficient evidence of carcinogenicity in humans</td>
</tr>
<tr>
<td>2a</td>
<td>Agents probably carcinogenic to humans</td>
<td>There is limited evidence of carcinogenicity in humans, but sufficient evidence of carcinogenicity in experimental animals</td>
</tr>
<tr>
<td>2b</td>
<td>Agents possibly carcinogenic to humans</td>
<td>There is limited evidence of carcinogenicity in humans, and less than sufficient evidence of carcinogenicity in experimental animals</td>
</tr>
<tr>
<td>3</td>
<td>Agents unclassifiable as to carcinogenicity in humans</td>
<td>There is inadequate evidence of carcinogenicity in humans, and inadequate or limited evidence in experimental animals</td>
</tr>
<tr>
<td>4</td>
<td>Agent probably not carcinogenic to humans</td>
<td>There is evidence suggesting a lack of carcinogenicity in humans and in experimental animals</td>
</tr>
</tbody>
</table>
to children’s exposure to environmental risk factors have been published elsewhere [1].

METHODS

Children were defined by PINCHE as “human beings below the age of eighteen”. Research on exposure and effects from conception to birth were included in the analyses, and in some instances, preconception exposure was also taken into consideration. We analysed existing evidence on the impact of environmental risk factors on children’s health, from studies supported by the European Union and from international publications. Relevant EU studies funded under the Fourth and Fifth Framework Programme were collected using the databases of the EU Directorate General on Research and on Health & Consumer Protection. International scientific literature was searched by using the literature databases Pubmed, Embase and Toxline. The search focused on reviews and studies published in the last five years (1998–2003). Papers were sought that either specifically comprised data on children or on children as a sub-group; where appropriate, complementary publications were added to the database.

An evaluation system was developed to extract the important information from the studies which was entered on an evaluation form. The quality of the evaluated studies was assessed using quality criteria regarding the methods used and the handling and reporting of biases. The evaluation used a systematic framework to interpret the data and answer the following questions:

— Exposure: the routes and sources and levels of exposure in the regions of Europe.

— Epidemiology: what health effects were found in children exposed to the environmental stressor? How strong were the relations found?

— Toxicology: what were the health effects found in toxicological studies? What was the mechanism of effect?

Were children more susceptible than adults?

The information from the interpretation framework formed the basis for analysing the information from the research results and — later on — for prioritisation.

The criteria used for setting priorities for action regarding the environmental risk factors were:

— the number of children exposed and the dose;

— the nature of adverse health effects and the likelihood that these health effects will occur at the current exposure levels;

— the extent to which children are more susceptible than adults;

— the extent to which children are more exposed than adults; and

— the regulatory measures already in place as well as probable future developments in exposure patterns.

These criteria were not defined quantitatively but were used as qualitative guidelines by the PINCHE members for the process of prioritisation. When there were some indications of irreversible or severe adverse health effects but a lack of confirmatory scientific evidence, we applied the precautionary principle and recommended action.

RESULTS

Literature collection

Out of 219 publications that were found to be related to outdoor and indoor air pollutants and children, 120 references were evaluated and summarised using the evaluation form; 99 publications were either not applicable to children’s respiratory health, or were extensive reviews which were taken into account as a whole rather than being summarised. On neurotoxicity, 252 articles were identified, mainly non-review articles. Of these, 201 articles were evaluated using the evaluation form. The remainder were not considered because they were irrelevant. For the noise theme, 222 relevant references were identified. Only 30 articles were evaluated using the evaluation form, because most partners working on noise preferred writing the results directly, without the additional step of systematic evaluation of the literature. For the carcinogenicity theme, 324 articles of relevance were identified and 167 references were evaluated. The remaining articles were either not related to children’s health specifically or were not considered relevant for the current European situation.
Exposure to sulphur dioxide has declined considerably since the 1980s. This exposure is associated with increased upper and lower respiratory tract symptoms in children and some studies suggest an association with decreased birth weight [9,11].

Ozone
Ozone is the main ingredient of summer smog. Ozone concentrations in Europe regularly reach levels that can affect respiratory health, especially for children. The health effects of ozone exposure seem to be greater in asthmatic children and in children who are exercising or playing outside more often when ozone levels are high [12].

Environmental Tobacco Smoke
All children are exposed to environmental tobacco smoke (ETS) to some extent. An estimated 40% of children in Europe are exposed in their homes by one or two parents smoking [13]. About 20–30% of women actively smoke during pregnancy. Children, especially when exposed perinatally, are very vulnerable to environmental tobacco smoke. The mean birth weight of foetuses exposed to maternal smoke is reduced by about 250 grams, and the mean birth weight of foetuses exposed to maternal passive smoking is reduced by 25 to 100 grams [14]. Infants of lower birth weight and gestational age are at increased risk for neonatal mortality and morbidity. The risk of Sudden Infant Death Syndrome (SIDS) in children of smoking mothers is almost twice as high as of non-smoking mothers [15]. Postnatal ETS exposure due to parental smoking is associated with: 60% increase in the risk of lower respiratory tract infections, 24–40% increased risk of chronic respiratory symptoms and 21% increased risk of asthma [16]. There is increasing evidence that ETS exposure is linked to intellectual impairment [17]. ETS is also carcinogenic: polycyclic aromatic hydrocarbons and nitrosamines, two compounds of ETS, may play major roles in genotoxicity (induction of DNA damage).

Allergens
The number of children sensitised to allergens is increasing. Exposure to allergens can induce symptoms in persons already sensitised, and exposure can cause sensitisation,
mainly in young children. It has been assumed that exposure to allergens early in life would reduce the incidence of respiratory allergies, but this is currently debated. Air pollution increases susceptibility to allergic reactions in sensitised individuals [18,19]. Sensitised children should be sheltered from exposure to allergens or pollutants. Exposure can be reduced, for instance by taking the pollen season into consideration in planning holidays or by the encasing of mattresses and bedding material.

**Endotoxins**

Endotoxins are toxic molecules derived from the outer cell wall of gram-negative bacteria. They are present in varying amounts in most indoor environments, particularly where domestic animals are present. Endotoxins are associated with induction of airway inflammation, reversible bronchoconstriction, wheezing and asthma exacerbations [20]. On the other hand, exposure to endotoxins has also been suggested to protect against allergic sensitisation [21,22]. This discussion is ongoing at present.

**Moulds**

Moulds are ubiquitous in the outdoor environment and can enter the home not only through doorways and windows, but also by ventilation and air conditioning systems. Most moulds proliferate in moist environments. The problem of indoor moulds has increased during recent decades because of the development of more well insulated houses. The association between dampness and moulds and the prevalence of wheeze and cough has been confirmed in several studies with odds ratios in the range of 1.5–3.5 [23]. The dampness that promotes mould growth also encourages infestation with house dust mites or insects [24]. Mould growth could thus also be a marker for other causes of illness.

**Cleaning products and chlorination by-products**

Several cleaning products are classified as irritants to lung, skin, and eyes. The most hazardous cleaning products are already no longer used. Sodium hypochlorite is the main ingredient in household (chlorine) bleach, the most common cleaner accidentally swallowed by children. Ammonia can be found in some cleaning products. Ammonia fumes are very irritating to the eyes, nose and airways. When sodium hypochlorite is mixed with ammonia or acid-based cleaners (including vinegar), it releases highly toxic gases: chlorine and chloramines. Short-term exposure to chloramine gas may cause mild asthmatic symptoms or more serious respiratory problems. Because hypochlorite products carry mandatory warning labels, such exposures are limited to accidents or the results of deliberate misuse. Therefore, children’s exposure to cleaning products is not likely to cause acute health effects frequently in the future. However, chronic exposure may increase the risk of asthma symptoms [25].

Chlorination by-products are produced when the disinfectant chlorine reacts with organic matter in tap water or swimming pool water. Some of the chlorination by-products are carcinogenic [26]. Whether chronic exposure by drinking chlorinated tap water might lead to bladder or colon cancer has not been resolved. Drinking of chlorinated tap water has been associated with adverse reproductive outcomes: low birth weight (LBW), small for gestational age (SGA) infants, preterm delivery, spontaneous abortions, stillbirth and birth defects [27]. However, these risks are small compared to the risks resulting from drinking water that has not been disinfected. In a recent study, regular attendance at indoor chlorinated pools was found to be associated with the risk of developing asthma in atopic children [28]. The risk seems to be greater for children and especially babies who are more susceptible and who attend small pools which are shallow, hot and polluted.

**Formaldehyde**

Formaldehyde, one of the most ubiquitous indoor air contaminants, is found in cigarette smoke and is released from building material. Some epidemiological studies connect formaldehyde exposure, even at low concentrations, with an increased risk of asthma [29,30]. Formaldehyde has been classified as a group 1 carcinogen by IARC. It can, in concentrations found in occupational settings, cause nasopharyngeal cancer and is also suspected to cause leukaemia [31]. All children are exposed to formaldehyde with usually higher concentrations found indoors.
Children are exposed to pesticides in food, water, breast milk and contaminated soil. In addition, pesticides can be ingested, inhaled or absorbed through the skin. In an EU monitoring study in Sweden in 2003, two out of 101 samples from foods specifically for infants or young children had residue levels exceeding the Minimum Risk Levels (MRLs) [43]. There is evidence that children, especially the foetus and neonates, are more susceptible to pesticide toxicity. This evidence is supported by similar findings in neonates of other species [44] and may be partly due to lower levels of detoxifying enzyme systems [45].

Organohalogen compounds
Even under current exposure levels, dioxins and dioxin-like polychlorinated biphenyls pose a health threat mostly to the developing foetus (via in utero exposure) and newborns (via breast milk). Effects on cognitive and behavioural development, on bone marrow, on growth and reproductive development are most probably persistent. Toxic effects on thyroid metabolism detected at birth, and liver function abnormalities are no longer seen at 2 and 8 years of age [46]. Nowadays, the levels in breast milk are 50% lower in western European countries than in 1990, thanks to reduction policies. This lowering has not been as effective for PCBs, although their production was banned in 1977. However, the advantages of breast feeding outweigh in most cases the pollutant-related disadvantages. A Tolerable Daily Intake (TDI) for dioxins and dioxin-like PCBs of 1 to 4 pg I-TEQ per kg bw/day was recommended for dioxins by the World Health Organisation in 1998 [47]. Current mean intake of dioxins in European countries is within this range of TDI levels. However, it should be noted that the WHO's ultimate goal is to reduce human intake levels below 1 pg TEQ per kg bw/day.

The class of polybrominated flame retardants studied in PINCHE is the group of polybrominated diphenyl ethers (PBDEs). The widespread and rapidly increasing use of PBDEs, their persistence, and structural similarities to PCBs have raised concern about their effects on human health [48]. Children are exposed to PBDEs through diet, mainly through fish, meat and milk. Limited data are available on human health effects in adult populations,
and these data are mainly from occupational exposure studies. Exposure to penta- and octa-BDE, two congeners of PBDE, lead to learning impairment and impaired motor behaviour in rodents [49,50]. Exposure to penta-, octa- and deca-BDE has effects on thyroid homeostasis in animals [48,50].

The EU has banned the production and use of penta- and octa-BDE since 2004, however, exposure will continue during the next few decades. Data on exposure and toxicity regarding deca-BDE are scarce. Therefore, based upon current scientific evidence, health effects cannot be linked to human exposure to deca-BDEs [51].

**Metals**

Chronic exposure to arsenic-contaminated water has been associated with skin cancer, cutaneous lesions, peripheral vascular diseases, abdominal pain, diarrhoea and nausea [52,53]. Arsenic compounds are classified by IARC as carcinogenic to humans (IARC group 1). Increased exposure has been associated with adverse pregnancy outcomes (stillbirths and miscarriages). Several million European children may be exposed to drinking water in which the limits of 10 µg/l are exceeded. In some areas near industrial sites, exposure through soil (hand-mouth behaviour), dust, and home-grown food might be above the maximum permissible oral intake level as set by the US EPA or by FAO. Based on current levels of arsenic in the air, it is expected that the present exposure of children in Europe will induce hundreds of cancers later in life [54].

Cadmium is a known human carcinogen, IARC group 1; it induces cancer upon inhalation [55]. Chronic exposure is associated with health effects such as impaired kidney function and osteoporosis. This has been observed at current levels of exposure in some countries [55]. Children’s urinary cadmium levels have been associated with immune response modification [56]. Experimental animal studies suggest that cadmium exposure early in life may induce neurotoxic and behavioural effects [57]. Emission of cadmium has been reduced by 40% between 1990 and 1999 [58]. Children are exposed to cadmium mainly through food and through inhalation of environmental tobacco smoke. Children in eastern Europe and children living near copper smelters are exposed to higher cadmium levels. A few percent of children in Europe have a cadmium intake that exceeds the tolerable daily intake (TDI) [59].

For chromium (VI) compounds as well as for nickel (both classified by IARC as group 1 substances) the cancer risks for children were evaluated as being low at current child exposure levels [60–62]. A link has been suggested between inhaled manganese and the central nervous system and cognitive problems, reduced fertility and pulmonary effects [63,64]. However, insufficient manganese intake can also lead to adverse health effects [65]. Lead poisoning in children causes reduced birth weight, anaemia, impaired motor functioning, hearing loss, reduction in IQ, behavioural problems, puberty delays, cancer, and damage to brain, liver and kidney [66,67]. Currently, 10 µg/dl is the blood lead level (PbB) above which there is concern for health; however, recent data suggest that there is no threshold below which lead is not toxic to the developing central nervous system. Many studies address the cognitive effects of lead in children. A decrease of 2–3 points in IQ with an increase from 10 to 20 µg/dl PbB was found in a meta-analysis [68]. Recent studies confirmed a decrement of 4.6 points of IQ for each 10 µg/dl increase of PbB but found a larger effect of a loss of 7.4 IQ points for a PbB change between 0 and 10 µg/dl [69]. Because of interventions such as the ban of leaded petrol, blood lead concentrations in children have fallen substantially in most European countries [70,71]. The majority of children in Europe are, however, still exposed to lead, mainly via food and air. Lead in paint is the major source of lead in older homes. Lead is also present in tap water from household plumbing systems containing lead. Also tobacco and tobacco smoke contain lead. Soil lead from leaded gasoline and pulverised lead-based paint is a source of human exposure which might be more important as a source than intact lead-based paint [68]. Infants are also exposed to lead through maternal milk. A pooled analysis of 12 studies confirms that lead-contaminated house dust is now the major source of lead exposure for children [68]. Indoor floor dust accounts for approximately 50% of
a young child’s total lead intake. Mean blood levels are below 5 µg/dl in western Europe and between 5 and 10 µg/dl in eastern Europe. Up to 5% of English children have blood lead levels exceeding 10 µg/dl [72].

Mercury and its compounds are highly toxic. High doses can be fatal to humans, but even relatively low doses can have serious adverse neurodevelopmental impacts, and can be linked to harmful effects on the cardiovascular, immune and reproductive systems [73,74]. Methymercury passes both the placental barrier and the blood-brain barrier, inhibiting cognitive development even before birth. Two large-scale longitudinal cohort studies were performed at the Faroe Islands and the Seychelles. The Faroe Islands study showed several neuropsychological deficits to be associated with methyl mercury levels in cord blood [75,76]. No detectable adverse effects were found in relation to methyl mercury levels in maternal hair grown during pregnancy in the Seychelles study [74,77]. The difference has been explained by the fact that in the Seychelles, exposures were entirely from nearly daily fish consumption, while in the Faroe Islands, exposure was mainly attributable to episodic consumption of pilot whale. Pilot whales have much higher levels of mercury than typical ocean fish and also contain other contaminants such as PCBs.

Exposure to methylmercury mostly occurs via consumption of fish and seafood. Most people in the coastal areas of the Mediterranean countries and around 1–5% of the population in central and northern Europe ingest amounts close to the reference dose of 0.1 µg/kg bw/day. Children are more exposed than adults, because of relatively higher food intake, and nursing infants are more exposed because of exposure through breast milk [78].

Other carcinogens
Asbestos, beryllium, coal tar pitches and ethylene oxide are IARC 1 compounds, indicating that these compounds are proven to be carcinogenic to humans. Children’s exposure to these compounds is generally very low in Europe. Acrylamide, 1,3-butadiene, n-nitrosodimethylamine and n-nitrosodiethylamine are IARC 2a compounds, meaning that these compounds are probably carcinogenic to humans. For children, the levels of exposure to these carcinogens are very low as well.

Polycyclic aromatic hydrocarbons (PAHs) as a group are considered to be proven human carcinogens, associated with the induction of lung cancer by inhalation [79]. No direct evidence exists regarding lung carcinogenicity of PAHs in children, or in adults after exposure during childhood. However, childhood exposure to ETS (of which PAHs are one of many carcinogenic components) has been linked with increased lung cancer risk later in life [80]. Children are exposed via inhalation of PAHs (also present in tobacco smoke), via consumption of PAH-containing foods (mainly grilled or smoked meat and fish) and via ingestion of PAH-contaminated soil and household dust [79]. Intrauterine growth restriction (IUGR) and low birth weight (LBW) were observed at PAH concentrations higher than 15 ng/m³, the concentrations encountered in highly polluted urban areas in Europe [81]. There appears to be a downward trend in outdoor air PAH concentrations as a result of interventions.

Noise
From the international literature and extended reviews performed on noise in relation to children’s health [82–84] it can be concluded that children are more susceptible to acquiring noise-induced hearing impairment. Exposure to transport noise can lead to annoyance, stress responses, cognitive impairment and possibly cardiovascular problems. Exposure to noise in schools is related to deficits in reading and recognition memory [85,86]. Cognitive impairment related to aircraft noise exposure may be reversible if exposure is terminated, as seen in the Munich airport studies [87].

Leisure noise is a hazard to hearing in young people, both children and adolescents. Many young people are exposed to high noise levels by using personal audio players, such as MP3 players, and by visiting discothèques. Also toys and firecrackers can produce very high noise exposure levels transiently. Prolonged exposure to loud music may lead to permanent hearing threshold shift, and to temporary as well as permanent tinnitus (ringing in the ear) [88]. Studies of noise exposure in neonatal intensive care units have
shown that noise levels can reach high levels in incubators, but these levels do not often occur, and exposure has only been proven to be related to sleep disturbance, not to other health effects [84].

Solar radiation
Exposure to solar radiation is inevitable and necessary for vitamin D production. The main adverse effects on health are due to the high-energy ultraviolet radiation (UV). UV intensity has been increasing since 1980 due to destruction of the stratospheric ozone layer. Exposure to UV and solar radiation during childhood may cause skin cancer in childhood or adulthood. It has been suggested that exposure to solar radiation during childhood contributes more to developing skin cancer than similar exposure during adulthood [89]. Over 90% of non-melanoma cancers can be attributed to exposure to UV-B while UV-A may be a cause of malignant melanoma [89]. UV exposure may be associated with non-Hodgkin’s lymphoma [90]. On the other hand, exposure to UV results in synthesis of vitamin D, and vitamin D may lead to decreased risk of non-Hodgkin’s lymphoma [91]. UV exposure can cause eye damage including retinal damage, snow blindness and in the long term cataract. Exposure to solar radiation depends on the latitude where children live and their behaviour. Susceptibility of children to the carcinogenic effects of solar radiation depends on the skin type.

Ionising radiation
Ionising radiation includes exposure from natural and man-made radiation sources which may be external, such as X-rays and gamma rays, or internal, due to the ingestion or inhalation of radioactive substances. Ionising radiation is genotoxic and carcinogenic, without a dose threshold. Radon is a naturally occurring radioactive gas. It makes up about half the total annual exposure of humans to radiation. Long-term exposure to radon is associated with lung cancer in adults [92]. The foetus is at particular risk from thyroid and bone-seeking isotopes. There is high cell-turnover during childhood, and the processes associated with cell division are well known to be more radiosensitive. Background radiation probably accounts for 10% of all childhood and adult cancers. Because background radiation is difficult to reduce, the main focus should be on avoiding additional exposure and unnecessary increases in exposure. Radon is a special case because intervention is possible.

CONCLUSIONS
Based upon the information on health effects and exposure, and using the criteria mentioned above in a qualitative manner, PINCHE ranked the priorities for the reviewed environmental risk factors into high, medium and low. The priority ranking was prepared realising the shortcomings of such a qualitative approach and was not intended as an exclusive or final list. It should be seen rather as an indication of PINCHE’s prioritisation for action. All actions suggested need to be done and under ideal circumstances all should be done immediately.

High priority
Reducing exposure to nitrogen dioxide, particulate matter and diesel engine exhaust has a high priority, because children’s susceptibility is high for most symptoms, and because exposure of children in Europe to these air pollutants is very high, leading to respiratory effects and neonatal mortality. Also exposure reduction of benzene has a high priority, because exposures in urban areas are often high, leading to additional cases of cancer. Reducing children’s exposure to environmental tobacco smoke is of high priority, because children are more susceptible than adults, most children are exposed and exposure is associated with many severe health effects. Exposure reduction of allergens is given a high priority, because many children experience allergic symptoms. Reduction of exposure to mercury in Europe still has a high priority. Many children are exposed to mercury levels that are shown to be associated with serious health effects.

Medium priority
PINCHE concludes that exposure reduction of ozone is of medium priority. In children, health effects of exposure to ozone can be severe, but the formation of ozone can-
not easily be changed by policy measures. Also exposure reduction of moulds is of medium priority, because exposure to mould, or associated types of exposure, leads to respiratory symptoms. Exposure reduction of pesticides has a medium priority in general, but this priority differs greatly between European regions. In the North-West of Europe exposure is low, but in Central and Eastern Europe, children’s exposure to pesticides is higher because of a higher pesticide use and because of a small-scale farming that brings children into closer contact with pesticides. There is a high priority to reduce exposure in those areas. The priority for reducing exposure to formaldehyde is medium. Many children are exposed to formaldehyde at levels that cause respiratory health effects. Reduction of exposure to polychlorinated biphenyls (PCBs) and dioxins is of medium priority, because exposure levels have decreased, but children are susceptible and the health effects demonstrated at current exposure levels are serious. Although no health effects are expected at current exposure levels to polybrominated biphenyl ethers (PBDEs), their priority level is medium, because of the lack of toxicity data and because the levels in the environment are rapidly increasing. Similarities with other organohalogenes regarding possible toxic mechanisms and the long persistency of these substances also suggest concern. PINCHE recommends continuation of monitoring studies and toxicity studies on deca-BDEs and other BDEs. PINCHE further concludes that reducing exposure to transport noise, noise in schools, noise in discothèques and noise from personal audio players has a medium priority. Many children are exposed, children are more susceptible to develop some health effects, and exposure can lead to various serious health effects. Arsenic has a medium priority, because in some parts of Europe, mainly in Eastern Europe, children and pregnant women are exposed to levels causing adverse pregnancy outcomes and other health effects. Also the priority for cadmium is medium, because some children in Europe are exposed to high levels, leading to several health effects. Even though current lead exposures can still lead to severe adverse health effects, PINCHE rates the priority of lead reduction as medium, because most sources of lead have been regulated. Exposure to solar and UV radiation is of medium priority: exposure may lead to skin cancer, but exposure is also necessary for vitamin D production. More research on the amount of UV radiation necessary for vitamin D production is necessary. Exposure reduction to ionising radiation, including radon, is concluded to be of medium priority. Ionising radiation is suspected to cause a substantial part of all cancers, but mainly through natural background radiation that cannot be changed. Radiation from man-made sources could be reduced, but the health benefits of medical use of radiation should be acknowledged. Reduction of radon concentrations indoors is possible, though effective measures can be costly. Because of the consistent evidence that exposure to atmospheric polycyclic aromatic hydrocarbons (PAHs) at current levels may cause increased risks of cancer and intrauterine growth retardation, reduction of PAHs is of medium priority.

**Low priority**

Reduction of exposure to sulphur dioxide is of low priority, because current exposures are low due to policy measures taken in the past. Exposure reduction of endotoxins is of low priority, because respiratory effects may occur, but exposure may also lead to fewer allergies. Some of the PINCHE partners who specialised in noise were of the opinion that exposure from fire crackers and toys is very important, because the noise levels can cause instant and non-reversible hearing impairment, but the majority concluded that although these exposures are very intense, they are infrequent, and therefore, may have less impact on auditory health than other sources of prolonged noise exposure. The priority of reducing exposure to cleaning products is low, because of the small health effects associated with the cleaning products currently in use. The priority for reducing exposure to chlorination by-products is low, because disinfection of water is necessary, and because the health effects caused by chlorination by-products are not clear. Exposure reduction to tetrachloroethylene, trichloroethylene and vinylchloride is of low priority, because exposure levels are low and the cancer risk is very low. Expos-
Table 2. Factors with high priority

<table>
<thead>
<tr>
<th>Factors studied</th>
<th>Argument for classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen dioxide, particulate matter, diesel engine exhaust</td>
<td>Children are susceptible to the majority of the symptoms caused by these pollutants. Current exposure to these pollutants is high in Europe and leads to many respiratory effects</td>
</tr>
<tr>
<td>Benzene</td>
<td>Many children are exposed to high levels and there is a strong causal relationship with cancer</td>
</tr>
<tr>
<td>Environmental Tobacco Smoke</td>
<td>Many children are exposed and exposure is associated with many health effects</td>
</tr>
<tr>
<td>Allergens</td>
<td>Many children experience allergic symptoms and the societal impact is great</td>
</tr>
<tr>
<td>Mercury</td>
<td>Many children are exposed to levels that are shown to be associated with serious health effects</td>
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</table>

Table 3. Factors with medium priority

<table>
<thead>
<tr>
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<th>Argument for classification</th>
</tr>
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<tbody>
<tr>
<td>Ozone</td>
<td>Ozone leads to respiratory effects, but the formation of ozone cannot (easily) be changed</td>
</tr>
<tr>
<td>Mould</td>
<td>Exposure to mould (or associated types of exposure) leads to respiratory problems</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Exposure is low in Northern Europe, but children’s exposure may be higher in other regions because of higher pesticide use (due to small-scale farming and domestic use) and this exposure may cause health effects</td>
</tr>
<tr>
<td>Volatile Organic Compounds (VOCs)</td>
<td>Exposure occurs in different settings, and this can lead to some irritation and nervous system effects</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Formaldehyde exposure is ubiquitous because of its widespread use. There are situations in which it leads to respiratory effects</td>
</tr>
<tr>
<td>Dioxins and Polychlorinated Biphenyls (PCBs)</td>
<td>Even though exposure levels have been decreasing, the health effects demonstrated at these levels are potentially serious</td>
</tr>
<tr>
<td>Brominated flame retardants</td>
<td>Although there are no health effects expected at current low levels, toxicity data are lacking and levels are increasing rapidly. Because of their persistence and their similarity to polychlorinated biphenyls (PCBs), concern has been raised about the effects on human health. Their priority may change in the future when more toxicity data are available</td>
</tr>
<tr>
<td>Noise in discothèques and from personal audio devices</td>
<td>Adolescents are exposed to high noise levels, which can lead to hearing impairment, including tinnitus</td>
</tr>
<tr>
<td>Transport noise and noise in schools</td>
<td>Many children are exposed to levels that may lead to adverse effects, mainly on cognition</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Children and pregnant women are exposed to levels causing health effects, but only in some parts of Europe</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Some children in Europe are exposed to levels that may cause health effects</td>
</tr>
<tr>
<td>Lead</td>
<td>Most sources of lead exposure have been regulated, but lead is still a problem in some places and is associated with severe health effects</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Exposure can lead to skin cancer, but vitamin D production is important as well. Research should be encouraged on the amount of solar radiation necessary for vitamin D production</td>
</tr>
<tr>
<td>Ionising radiation</td>
<td>Ionising radiation is suspected to be responsible for a substantial part of all cancers, but mainly from background levels that cannot be changed. Human-made (internal) exposure may cause additional cancer, but beneficial effects of medical radiation therapy should also be taken into account</td>
</tr>
<tr>
<td>Radon</td>
<td>Radon is associated with lung cancer. Exposure in dwellings can be reduced, though effective measures can be costly</td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons (PAHs)</td>
<td>Current exposure to PAHs may lead to lower birth weight and intrauterine growth retardation. These exposure levels are associated with a small risk of cancer</td>
</tr>
</tbody>
</table>
sure reduction of chromium and nickel has a low priority, because the cancer risk is low at current exposure levels in children. Because manganese is a micronutrient and because health effects at current exposures are small, the priority for reducing manganese exposure is concluded to be low. The carcinogens such as asbestos, beryllium, coal tar pitches, ethylene oxide, acrylamide, 1,3-butadiene, n-nitrosodimethylamine and n-nitrosodiethylamine are given a low priority, because children’s exposure is very low, and therefore the risk of developing cancer due to these exposures is also very low.

The results of the prioritisation and the arguments used for classification are summarised in tables 2, 3, and 4.

### Table 4. Factors with low priority

<table>
<thead>
<tr>
<th>Factors studied</th>
<th>Argument for classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide (SO$_2$)</td>
<td>Current exposure levels are low due to policy measures taken in the past</td>
</tr>
<tr>
<td>Endotoxins</td>
<td>Respiratory effects from exposure are not clear and early exposure may benefit health</td>
</tr>
<tr>
<td>Cleaning products</td>
<td>Children’s exposure is not suspected to lead to severe health effects</td>
</tr>
<tr>
<td>Chlorination by-products</td>
<td>Disinfection of water is necessary and health risks of exposure to chlorination by-products from drinking water or from pool water are not clear</td>
</tr>
<tr>
<td>Noise from toys and firecrackers</td>
<td>Although the exposure level can be high and can occur at a very young age, extreme exposure does not occur often</td>
</tr>
<tr>
<td>Noise in neonatal intensive care units</td>
<td>Exposure has only been proven to be related to sleep disturbance and not to other health effects</td>
</tr>
<tr>
<td>Chromium VI</td>
<td>Children’s exposure is low</td>
</tr>
<tr>
<td>Nickel</td>
<td>Environmental exposure causes a very low cancer risk</td>
</tr>
<tr>
<td>Manganese</td>
<td>Exposure is low and manganese is a nutrient</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Children’s exposure is very low</td>
</tr>
</tbody>
</table>

The DISCUSSION

The different stakeholders of PINCHE, mainly scientists, NGOs and industry, coming from different areas in Europe, did not reach consensus on whether or not it was feasible or even desirable to assess the priorities for environmental health of children in Europe. Once that issue was settled, determining the priorities for such a broad range of exposure factors proved to be difficult because no one had extended knowledge on all of these exposure factors, because the health effects related to the different exposure factors are very different and therefore difficult to compare, and also because priorities differ from region to region. Nevertheless, a priority list has been created, using the qualitative criteria mentioned, because it was felt that informing the EU and Member States on relative priorities is necessary to focus EU policy on the stressors that should be targeted first. Although priorities in some regions of Europe may differ from this list, the list provides an overview of which environmental hazards we see as being the most immediately threatening to children’s health in Europe. There has recently been a publication which uses the WHO “burden of disease” principle to evaluate the burden of disease attributable to selected environmental factors on children [93]. This publication also concludes that there is an urgent need to reduce children’s exposure to certain environmental factors such as air pollution. However, no attempt is made to prioritise these factors against others as has been done in PINCHE.

We feel that the present overview of environmental risk factors and the urgency of preventing negative effects on children’s health caused by those risk factors represent important information for the policy makers of the European Union as well as for its Member States.

PINCHE’s partners agreed to give high priority to the reduction of exposure to outdoor air pollutants and environmental tobacco smoke. The main discussion within the group concerned the priority setting for the brominated...
flame retardants, lead, PCBs, dioxins, allergens, pesticides, ionising radiation and some of the noise sources. PCBs, dioxins, lead, pesticides and ionising radiation clearly all have severe effects on children at present exposure levels. However, some policy measures are already in place and exposure levels are declining or are expected to decline in the future. For this reason, their priority was set as medium.

The priority setting for pesticides was based on the literature related to pesticides used in agriculture. There is, however, an increase in the use of pesticides in home and gardening applications in Europe, which might lead to reconsideration of the medium priority.

For polybrominated biphenyls, the discussion was based on the use of the precautionary principle in the present situation of an expected rapid increase of these substances in the environment, versus the lack of sufficient data demonstrating a clear direct toxic effect. Priority was set as medium.

For noise, there was a difference of opinion regarding the effects of short exposures to high intensity noise versus long-term effects of lower level noise from various sources. Also here, a medium priority level was chosen.

Allergens were discussed as well, because exposure to allergens is very difficult to change outdoors, but also because the measures aimed at reducing allergen exposures indoors are often not effective. Because many children are sensitised to allergens and because allergic symptoms can also be reduced by improving outdoor air quality, their priority was rated as high.

It should be made clear that exposure factors that were rated with a 'low' priority, for example many carcinogens to which children's exposure is low, should not be considered as causing no harm to children's health. It means that, at present, exposure reduction of these compounds is of lower priority than that of the other compounds. However, exposure reduction should be carried out in hotspots, and in cases where exposure reduction is relatively easy to achieve, it should certainly be done.

In PINCHE, many environmental health hazards were studied, but this did not include exposure to all the potentially harmful environmental agents for children. The risk factors not studied in PINCHE were, for example, non-ionising radiation, phthalates and some endocrine disrupting chemicals. Because of this, and because exposure of children may change and more evidence on health effects may be found, the priority list should be revised when new information becomes available. The precautionary principle should apply under all circumstances and safe levels for children should be the target.

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REFERENCES


44. Hughes J, Capleton A, Courage C. A review on the effects of low-level exposure to organophosphate pesticide on fetal and childhood health. Berlin: Bundesinstitut für gesundetlichen Verbraucherschutz und Veterinärmedizin (BgVV); 2002.


55. Jarup L, Berglund M, Elinder CG, Nordberg G, Vahter M. Health effects of cadmium exposure — a review of the
78. SCOOP. Assessment of the dietary exposure to arsenic, cadmium, lead and mercury of the population of the EU Member States. Brussels: European Commission; 2004.
81. Dejmek J, Solansky I, Benes I, Lenicek J, Sram RJ. The impact of polycyclic aromatic hydrocarbons and fine par-


