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# Human exposure to trace elements through the skin by direct contact with clothing: Risk assessment

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ABSTRACT

Metals in textile products and clothing are used for many purposes, such as metal complex dyes, pigments, mordant, catalyst in synthetic fabrics manufacture, synergists of flame retardants, antimicrobials, or as water repellents and odour-preventive agents. When present in textile materials, heavy metals may mean a potential danger to human health. In the present study, the concentrations of a number of elements (Al, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Sc, Se, Sm, Sn, Sr, Tl, V, and Zn) were determined in skin-contact clothes. Analysed clothes were made of different materials, colours, and brands. Interestingly, we found high levels of Cr in polyamide dark clothes (605 mg/kg), high Sb concentrations in polyester clothes (141 mg/kg), and great Cu levels in some green cotton fabrics (around 280 mg/kg). Dermal contact exposure and human health risks for adult males, adult females, and for $<1$-year-old children were assessed. Non-carcinogenic and carcinogenic risks were below safe ($HQ<1$) and acceptable ($<10^{-6}$) limits, respectively, according to international standards. However, for Sb, non-carcinogenic risk was above 10% of the safety limit ($HQ>0.1$) for dermal contact with clothes.



## 1. Introduction

In recent years, the textile has become one of the most important industries, contributing significantly to economic growth in the global economy. Because textile manufacturing is a labour-intensive industry, developing countries are able to utilize their labour surplus to enter the market and begin the process of building an industrial economy. Textile production and consumption is an increasingly global affair as production continues in developing countries, which have noted an explosion in the growth of their textile exports, meaning textile for a number of countries a significant portion of their total exports.

The textile and clothing industry comprises a lot of activities, which goes from the treatment of raw materials to finishing activities such as bleaching, printing, dyeing, impregnating, coating, plasticizing, etc. As result of these activities, the main chemical pollutants present on textiles are dyes containing carcinogenic amines, metals, pentachlorophenol, chlorine bleaching, halogen carriers, free formaldehyde, biocides, fire retardants, and softeners (BfR, 2012; Brigden et al., 2013).

Metals in textile products and clothing are used for many purposes, such as metal complex dye (cobalt, copper, chromium, lead), pigments, mordant (chromium), catalyst in synthetic fabrics manufacture (antimony oxide), synergists of flame retardants ($Sb_2O_3$), antimicrobials (nanoparticles of silver, titanium oxide and zinc oxide), as well as like water repellents, and odour-preventive agents (Derden and Huybrechts, 2013; Muenhor et al., 2010; Panda, 2013; Simoncic and Tomsic, 2010; Stefaniak et al., 2014; Thiele, 2004; Wöhrle et al., 2012). When present in textile materials, toxic elements represent not only a major environmental problem in the textile industry, but also they may mean a potential danger to human health.

Metals can reach the human body mainly by ingestion and inhalation, but also by absorption through the skin from re-suspended particles of powder, which come from soils (Mari et al., 2007; Nadal et al., 2004), and through skin-contact clothes. Although exposure to metals rarely produce morbidity, or very rarely mortality, in the general population, the continued exposure to low levels of toxic elements such as arsenic (As), cadmium (Cd), mercury (Hg), or lead (Pb) has been associated with a number of adverse effects (García-Esquinas et al., 2015; Jaishankar et al., 2014; Nadal et al., 2004; Rodríguez-Barranco et al., 2014; Roy et al., 2011). Moreover, metals such as Cu, Co, Fe, Mn, or Zn among others, which are essential for humans, can also be dangerous at high exposure levels (Domingo, 1994; Lucas et al., 2015).

When evaluating the impact of not only essential but also toxic

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elements, an essential step is to establish whether the residual concentrations of these elements may derive in human health risks. For non-occupationally-exposed individuals, diet is doubtless the main route of human exposure (Linares et al., 2010). However, other minor routes must not be underestimated in the assessment of the total health risks. When assessing metal risks by dermal exposure through the skin-contact clothes, it must be taken into account that elements such as Co, Cr, Cu, and Ni, are skin sensitizers (Fage et al., 2014; Lidén et al., 2010; Simonsen et al., 2014) which may lead contact dermatitis, either allergic or irritant, being the latter the most frequent. In addition, Cr(VI) can lead not only to skin irritation, but also lo liver damage, pulmonary congestion, and cancer (Paine, 2001).

As dermal contact through skin-contact clothes might mean a non-negligible exposure pathway for elements, the purpose of the present study was to determine the concentrations of a number of elements in various skin-contact clothes. The analysed clothes were made of different materials (cotton, polyamide, polyester, spandex, and viscose), and were classified according to colour, brand, and eco-labelled categories. We estimated dermal contact exposures for adult males, adult females, as well as for $<1$ year-old children. Finally, the derived human health risks due to the dermal exposure to elements were also assessed.

## 2. Materials and methods

### 2.1. Sampling

Thirty-one pieces of clothing were randomly purchased in four kinds of stores (Sport stores, general clothing stores chains, brand clothing stores, and hypermarkets) from two cities (Reus and Tarragona) in the area of our university (Tarragona, Catalonia, Spain). The pieces of clothing purchased were the following: seven T-shirts, six blouses, six underpants, six bodysuits, and six baby pyjamas. They included coloured ($n=16$) and white pieces ($n=15$); branded ($n=10$) and unbranded ($n=21$) items, being 3 of them (among the 31 pieces) eco-labelled. Once at the laboratory, information such as, fibber, colour, place of production, etc. was recorded (Table 1). Moreover, density was obtained by cutting and weighing an area of dried cloth (Table 1).

### 2.2. Analytical procedure

Pre-treatment of the samples of the clothing was adapted from previous studies by Rezić and Steffan (2007) and Rezić (2009). Samples were dried and 0.5 g of each sample were digested with 10 mL of $HNO_3$ (32.5% Suprapur, E. Merck, Darmstadt, Germany) in a Milestone Start D Microwave Digestion System for 5 min at 105 °C, then 15 min at 180 °C, and finally, 20 min at 200 °C. After cooling, extracts were filtered and made up to 25 mL with ultrapure water. Extracts were kept frozen at $-20$ °C until elemental analysis. The concentrations of aluminium (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), scandium (Sc), selenium (Se), samarium (Sm), tin (Sn), strontium (Sr), thallium (Tl), vanadium (V), and zinc (Zn) were determined by means of inductively coupled plasma spectrometry (ICP-MS, Perkin Elmer Elan 6000). Blank and control samples, as well as reference materials (Spinach leaves, National Institute of Standards and Technology), were used to check the accuracy of the instrumental methods. The recovery percentages of the reference material ranged between 69% and

**Table 1**
Main characteristics of the skin-contact clothes analysed.

| N° | Cloth | Place | Materials | Made in | Colour | Density | Comments |
|---|---|---|---|---|---|---|---|
| **1** | T-shirt | Sport store | 84% PE; 16% Sp | Sri Lanka | Black | 18 | Breathable |
| **2** | Blouse | Chain store | 100% Vis | Turkey | Black | 9 | |
| **3** | Underwear | Chain store | 95% Cot; 5% Sp | Portugal | Garnet | 22 | |
| **4** | T-shirt | Chain store | 100% Cot | Bangladesh | Red | 14 | |
| **5** | Baby Pyjama | Chain store | 100% Cot | Portugal | Pink | 19 | |
| **6** | Bodysuit | Chain store | 100% Cot | China | Light blue | 25 | |
| **7** | Baby Pyjama | Brand store | 80% Cot; 20% PE | Rumania | Light blue | 23 | Ecosafe textiles |
| **8** | Bodysuit | Brand store | 100% Cot | Tunisia | Pink | 24 | Ecosafe textiles |
| **9** | Underwear | Brand store | 92% Cot; 8% Sp | Bulgaria | Olive green | 21 | |
| **10** | Blouse | Hypermarket | 100% Cot | India | Blue | 9 | |
| **11** | Bodysuit | Hypermarket | 100% Cot | India | Light blue | 20 | |
| **12** | Baby Pyjama | Hypermarket | 75% Cot; 25% PE | China | Light grey | 24 | |
| **13** | Blouse | Hypermarket | 100% Cot | Bangladesh | Green | 14 | |
| **14** | Underwear | Hypermarket | 92% PA; 8% Sp | Portugal | Black | 34 | |
| **15** | T-shirt | Sport Store | 100% PE | China | Green | 19 | Thermal |
| **16** | T-shirt | Sport Store | 100% PE | Tunisia | Blue | 16 | Breathable |
| **17** | Blouse | Brand store | 68% Cot; 28% PA; 4% Sp | Bangladesh | White | 13 | |
| **18** | Baby Pyjama | Brand store | 100% Cot | Bangladesh | White | 20 | Organic cotton |
| **19** | Bodysuit | Brand store | 100% Cot | Bulgaria | White | 20 | Organic cotton. EU Ecolabel |
| **20** | Underwear | Brand store | 92% PA; 8% Sp | Spain | White | 26 | |
| **21** | T-shirt | Sport Store | 100% PE | China | White | 17 | Breathable |
| **22** | Blouse | Brand store | 100% Cot | India | White | 6 | |
| **23** | T-shirt | Brand store | 100% Cot | Turkey | White | 15 | Organic cotton |
| **24** | T-shirt | Hypermarket | 100% Cot | Bangladesh | White | 15 | |
| **25** | Blouse | Hypermarket | 95% PE; 5% Sp | China | White | 20 | |
| **26** | Underwear | Hypermarket | 100% Cot | Spain | White | 18 | |
| **27** | Baby Pyjama | Hypermarket | 100% Cot | China | White | 17 | Fabric class C. |
| **28** | Bodysuit | Hypermarket | 100% Cot | China | White | 18 | |
| **29** | Underwear | Brand store | 95% Cot; 5% Sp | N.S. | White | 17 | |
| **30** | Baby Pyjama | Brand store | 100% Cot | Peru | White | 19 | |
| **31** | Bodysuit | Brand store | 100% Cot | Turkey | White | 21 | |

PE: polyester; Sp: spandex; Vis: viscose; Cot: cotton; PA: polyamide; N.S.: not specified; density in $mg/cm^2$.