

1 **Dermal exposure to bisphenols in pregnant women's and baby**
2 **clothes: Risk characterization**

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24 ABSTRACT

25

26 Textile manufacturing consists of a multiple-step process in which a wide range of chemicals is
27 used, some of them remaining in the final product. Bisphenols (BPs) are non-intentionally added
28 compounds in textiles, whose prolonged skin contact may mean a significant source of daily
29 human exposure, especially in vulnerable groups of the population. The present study aimed to
30 determine the levels of bisphenol A (BPA) and some BP analogs (BPB, BPF, and BPS) in 120
31 new clothes commercialized in Spain for pregnant women, newborns, and toddlers. In addition,
32 exposure assessment and risk characterization were also carried out. Traces of BPA were found in
33 all the samples, with a median concentration of 7.43 ng/g. The highest values were detected in
34 textile samples made of polyester. Regarding natural fibers, higher concentrations of BPs were
35 observed in garments made of conventional cotton than in those made of organic cotton, with a
36 significant difference for BPS (1.24 vs. 0.76 ng/g, $p < 0.05$). Although toddlers have a larger skin-
37 area-to-body-weight ratio, pregnant women showed higher exposure to BPs than children.
38 Anyhow, the non-carcinogenic risks associated with BPA exposure were below the unity, even
39 under the upper-bound scenario. However, risks could be underestimated because other exposure
40 routes were not considered in this study. The use of BPA has been restricted in some food-related
41 products; therefore, BPA should also be regulated in the textile industry.

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43 *Keywords:* bisphenols, BPA, dermal exposure, clothes, health risk assessment.

44 1. Introduction

45

46 Clothing should be based on safe materials, as everybody is in daily contact with them.
47 Over the years, the textile industry has been constantly on the rise, using a wide range of chemicals
48 and releasing many residues. Unfortunately, some of these substances, either intentionally added
49 or not, may remain in the final product at relevant concentrations. A wide range of chemicals, such
50 as bisphenol A (BPA), per- and poly-fluoroalkyl substances, dyestuffs, trace elements, and
51 brominated flame retardants, have been found in textile products (Iadaresta et al., 2018, Herrero et
52 al., 2019; Rovira and Domingo, 2019; Wang et al., 2019; Herrero et al., 2020; Zhu and Kannan,
53 2020; Sait et al., 2021; Souza et al., 2023; Undas et al., 2023).

54 According to the United States Environmental Protection Agency (US EPA), bisphenols
55 (BPs) are one of the most produced chemicals worldwide (US EPA, 2021). BPA (4,4'-(propane-
56 2,2-diyl)diphenol) is the primary compound, but because of its toxicity, increasing use, and
57 regulatory pressure, analog compounds have been introduced to replace it (Ding et al., 2022).
58 Among them, bisphenol F (BPF) and bisphenol S (BPS) are prevalent substances. However, the
59 levels of these compounds and the possible exposure pathways remain still understudied (Chen et
60 al., 2016; Siracusa et al., 2018; Wei et al., 2023).

61 Traces of BPA can be found in many products, including clothing, especially if made of
62 synthetic fibers. BPA may be used as an intermediate compound to manufacture dyes and
63 antioxidants during textile production. Besides, BPs can be added to the polyester -as an
64 intermediary- to improve its properties and lifespan and be used to create hygroscopic and
65 antistatic material with colorfastness for washing (Xue et al., 2017; Wang et al., 2019; Undas et
66 al., 2023).

67 Due to its widespread use and well-known endocrine-disrupting chemical (EDC), in recent
68 years, BPA has been extensively studied (Negev et al., 2018; Castro et al., 2021; Martínez et al.,

69 2021; Rovira et al., 2022). Although food intake is considered the most important exposure source
70 to BPs (Karrer et al., 2020), other potential pathways could also play a significant role. Since
71 dermal absorption of BPs may occur through direct skin contact with clothes worn the whole day,
72 this issue needs to be addressed, especially when considering vulnerable groups of the population
73 (Demierre et al., 2012; Xue et al., 2017; Freire et al., 2019; Rovira and Domingo, 2019; Sait et al.,
74 2021; Martínez et al., 2018, 2023; Souza et al., 2023).

75 A number of studies have reported an association between pre-and postnatal exposure to
76 BPA and the occurrence of adverse health outcomes in children, including behavioral problems,
77 asthma, obesity, alterations in immunity system and hormone levels, as well as changes in puberty
78 timing (Xue et al., 2017; Siracusa et al., 2018; Catenza et al., 2021). Moreover, studies in the
79 laboratory have been reported to cause cytotoxicity and neurotoxicity (Shimabuku et al., 2022). In
80 turn, BPA levels may be linked to various health problems such as breast and prostate cancer,
81 metabolic disorders, and diabetes (Chen et al., 2016; Xue et al., 2017; Siracusa et al., 2018; Freire
82 et al., 2019; Souza et al.; 2022). In addition, it has been pointed out that some BPA analogs, such
83 as BPS and BPF, show a similar -or even a higher- endocrine-disrupting activity than BPA
84 (Martínez et al., 2020; Gys et al., 2021). Recently, due to their potential hormonal and toxic
85 reproductive effects, the European Commission and the Scientific Committee on Consumer Safety
86 have modified the regulation concerning the levels of BPs in clothing. For it, the European
87 Chemicals Agency (ECHA) has adopted “Group Restriction” on BPs in the REACH (Registration,
88 Evaluation, Authorization, and Restriction of Chemicals) (ECHA/NR/22/08).

89 Human exposure to BPs is an issue of concern for public health. However, more
90 information is needed regarding the levels of BPs in textile products, as well as the evaluation of
91 dermal exposure. Considering the potential impact on human health, the risk assessment of this
92 EDC in clothing is required in order to ensure consumer safety, mainly for vulnerable groups of
93 the population (Xue et al., 2017; Freire et al., 2019; Rovira and Domingo, 2019; Wang et al., 2019;

94 Herrero et al., 2022a,b). In this context, this study aimed to determine the concentrations of BPA
95 and their analogs (BPS, BPB, and BPF) in pregnant women, newborns, and toddlers clothes, while
96 dermal exposure to these BPs and their associated risks were also assessed.

97

98 **2. Materials and methods**

99

100 *2.1. Chemicals*

101 Four BPs were included in this study: bisphenol A (BPA, CAS 80-05-7), bisphenol S (BPS,
102 CAS 80-09-1), bisphenol F (BPF, CAS 620-92-8), and bisphenol B (BPB, CAS 77-40-7).
103 Bisphenol A-*d*16 (BPA, CAS 96210-87-6) was used as an internal standard. All native analytical
104 standards and the labeled internal standard were purchased from Sigma-Aldrich® (St Louis, MO,
105 USA). The stock and working solutions were prepared in methanol (HPLC grade from Sigma-
106 Aldrich®) and stored at 4°C to avoid degradation. Chemicals used in the methodology included
107 acetone, dichloromethane, acetonitrile and methanol, all from Sigma-Aldrich®. High-purity water
108 was obtained from Milli-Q Synergy UV equipment (Millipore).

109

110 *2.2. Clothes*

111 One hundred and twenty (n=120) garments for pregnant women (n = 40), newborns (<12
112 months) (n = 30), and toddlers (12 - 36 months) (n = 50), which are commercially available in
113 Spain, were analyzed. The following clothing categories were included: T-shirts,
114 trousers/leggings/jeans, dresses, underwear (bra, panties, and socks), pyjamas, and bodysuits.
115 Most clothes (75%) were purchased from chain stores, hypermarkets, or tiny retailers in Tarragona
116 County (Catalonia, Spain), while the remaining 25% were purchased online. The detailed list of
117 each sample here analyzed is summarized in Table S1 (*Supplementary Information*).

118

119 *2.3. BPs chemical analysis*

120 The sample preparation methodology for determining BPs in textiles was adapted from that
121 reported by Freire et al. (2019). Briefly, approximately 0.5 g of each textile sample was accurately
122 cut, weighed, and placed in 15 mL glass centrifuge tubes, where they were spiked with 250 μ L of
123 the isotope-labeled surrogate solution (BPA-*d*16, 50 ppb). The extraction was performed by adding
124 7.5 mL of a mixture of acetone and dichloromethane (1:4, v/v). After sonication for 20 min and
125 centrifugation at 5000g for 7 min, the solvent was collected and filtered through a 0.2 μ m nylon
126 filter and transferred to another glass tube. The solvent was then evaporated to dryness and frozen.
127 Before the instrumental analysis, the residue was reconstituted with 250 μ L of acetonitrile.

128 BPs were quantified using ultra-performance liquid chromatography coupled with mass
129 spectrometry in tandem (UPLC–MS/MS). The used equipment was a 1290 UHPLC system
130 coupled to a QqQ/MS 6490 series from Agilent Technologies® (Santa Clara, CA, USA). The
131 chromatography separation of BP was carried out using a column ACQUITY BEH C18 column
132 (100 x 2.1 mm, 1.7 μ m) from Waters Corporation. Details of instrumental analysis and compound-
133 specific analytical parameters are shown in *Supplementary Information* (Tables S2, S3, and S4).

134

135 *2.4. Quality assurance and quality control*

136 Quality control was performed with procedural blanks and a spiked blank sample
137 containing 5 ng/g of BPA. An isotopically labeled internal standard (*d*16-BPA) was used to
138 increase the reproducibility of the analysis. All the samples were analyzed in triplicate to evaluate
139 their repeatability. After extraction, the extracts were frozen and then injected into the UPLC-
140 MS/MS in the same order as their preparation. Recoveries for all BPs in the quality-control spiked
141 samples ranged between 78% and 93%, with all coefficients of variation (CV) under 20%. The
142 ranges of the calibration curves were the following: 1.94 ng/g to 500 ng/g for BPA, 0.12 ng/g to
143 500 ng/g for BPB, 2.29 ng/g to 1000 ng/g for BPF, and 0.38 to 1000 ng/g to BPS. The limits of

144 detection (LOD) were 0.59 ng/g for BPA, 0.04 ng/g for BPB, 0.69 ng/g for BPF, and 0.12 ng/g for
145 BPS.

146

147 *2.5. Dermal exposure and human health risk assessment*

148 The concentration of BPs in clothes was used to calculate dermal exposure and BPA-
149 associated health risks. Exposure was estimated for pregnant women, infants aged <12 months,
150 and toddlers (12 to 36 months old). Dermal exposure was calculated based on the European
151 Chemical Agency (ECHA) (European Chemicals Agency, 2016) equation (Eq.1) and already
152 applied elsewhere (Rovira et al., 2015, 2017):

153

$$154 \quad \text{Exp derm} = \frac{F_{\text{cloth}} \times d_{\text{cloth}} \times A_{\text{skin}} \times F_{\text{contact}} \times F_{\text{pen}} \times T_{\text{contact}} \times n}{\text{BW}} \quad (\text{Eq.1})$$

155

156 where Exp derm corresponds to dermal exposure (mg/(kg·day)), Fcloth is the fraction of
157 element in clothes (mg/mg), dcloth is the density of the clothing (mg/cm²), Askin is the skin area
158 covered by the clothing (cm²), Fcontact is the fraction of contact area for skin (dimensionless),
159 Fpen is the penetration rate of the element (dimensionless), Tcontact is the duration of the clothing
160 skin contact (day), n is the number of events per day (1/day), and BW is the body weight (kg). The
161 dermal exposure parameters are summarized in Table 1.

162 Since BPA is the only bisphenol for which an oral reference dose (RfDo) has been
163 established, the non-carcinogenic risk was evaluated only for this compound. The Hazard Quotient
164 (HQ), defined as the quotient between exposure and the dermal reference dose (RfDd), was
165 calculated by multiplying RfDo with the gastrointestinal absorption factor (GAF), which was set
166 at 1. The RfD of BPA, whose value is 0.05 mg/(kg·day), was obtained from the Regional Screening
167 Level from the US EPA Preliminary Remediation Goals (US EPA, 2021).

168

169 *2.6. Data analysis*

170 Statistical analysis was conducted using the IBM SPSS Statistics software® version 28.0
171 (IBM Corp. Released 2020, Armonk, NY, USA). The Kolmogorov–Smirnov test was used to
172 assess the distribution of the values. In turn, the Student’s t-test or ANOVA test for data, following
173 a parametric distribution, or the Kruskal–Wallis tests for non-parametric data were used to assess
174 any statistical difference between groups. A difference was considered significant when the
175 probability was lower than 0.05 ($p < 0.05$). Non-detected (ND) levels were considered as one-half
176 of the limit of detection (LOD) ($ND = 1/2LOD$).

177

178 **3. Results and discussion**

179

180 *3.1. Occurrence of BPs in clothing*

181 The levels of bisphenol in clothes commercialized in Spain are given in Table 2. In
182 agreement with the widespread use of BPA, the highest concentrations corresponded to this EDC.
183 BPA was detected in all the samples, with a median value of 7.43 ng/g (range: 0.69-5872 ng/g). In
184 turn, BPB was detected in only 13% of the analyzed samples, with a median concentration below
185 the LOD (< 0.69 ng/g). BPF and BPS showed similar median values (1.01 ng/g and 1.04 ng/g,
186 respectively), but the range of concentrations was much higher for BPF (0.17-11333 ng/g for BPF
187 and 0.03-981 ng/g for BPS). Since these compounds can reach the manufacturing processes at
188 different stages, it is not possible to identify a single source of contamination. However, literature
189 data suggest that BPA may originate from textile packaging or, in clothing made of synthetic
190 fibers, it may also come from recycled plastic (Freire et al., 2019). BPs can be used in clothes
191 production to improve their performance and durability and as an intermediate in manufacturing
192 dyes (Xue et al., 2017; Freire et al., 2019).

193 In the current study, clothes for three vulnerable population groups (pregnant women,
194 newborns, and toddlers) were purchased. The results of the experimental analysis are depicted in

195 Figure 1. In general terms, higher concentrations (as median values) of BPs were observed in
196 pregnant women's clothes, while the minimum levels were found in newborns' clothes. A
197 significant difference between groups was observed only for BPA ($p=0.007$ between newborns
198 and pregnant women and $p=0.001$ between newborns and toddlers). Moreover, BPF was
199 predominant in items of pregnant women (286 ng/g) and BPA in newborns (5.49 ng/g) and toddlers
200 (18.7 ng/g). Higher levels of BPA were observed in underwear/panties clothing of pregnant women
201 and toddlers, with median concentrations of 10.4 and 37.9 ng/g, respectively. This exposure can
202 mean potential risks to women due to the direct contact of this clothing with the vagina mucosa,
203 which presents a greater probability of absorption of compounds in this region because of a large
204 blood flow (Nicole, 2014).

205 In order to understand the real distribution of BPs in clothing, data were treated according
206 to a number of parameters. Different manufacturing fibers were evaluated, including synthetic
207 (elastane, polyester, and polyamine) and natural (cotton) fibers. BPs levels according to the textile
208 material are summarized in Table 3. The highest median levels of the three analyzed BPs, BPA
209 (28.9 ng/g), BPF (1.56 ng/g), and BPS (2.38 ng/g), were observed in polyester fibers. Although
210 the difference was not statistically significant, the observed trend is in agreement with previous
211 data from the scientific literature (Xue et al., 2017). The material composition of clothing is an
212 important factor that influences the levels of BPs in new pieces (Xue et al., 2017; Wang et al.,
213 2019).

214 Samples made of natural fibers were classified according to the cotton production into
215 organic or conventional cotton. Organic fabrics are a sustainable alternative to textile materials
216 made with synthetic fibers. They are produced with natural and recycled raw materials, offering
217 less environmental impact (Goyal and Parashar, 2023). The present study examined organic cotton
218 as a more sustainable alternative to conventional cotton. Pesticides are not used in plantation
219 management, and there is a preservation of the soil nutrients. Interestingly, higher BPA, BPF, and

220 BPS concentrations were found in clothes made of conventional cotton than in organic garments,
221 with a significant difference for BPS (0.76 vs. 1.24 ng/g, $p < 0.05$).

222 Since BPA may be used as an intermediate compound in the manufacture of dyes in textile
223 production, the evaluation of colors is also important (Xue et al., 2017; Wang et al., 2019; Undas
224 et al., 2023). BPA and BPF were more predominant in grey clothes, while BPS levels were higher
225 in black clothes. When analyzing 77 textiles and infant clothing pieces, Xue et al. (2017) also
226 found higher levels of BPA in grey polyester (97%) socks for 6–12-month-old infants.

227 The area of textile manufacture of each item was also considered. Clothes made in the EU
228 showed lower levels of all the compounds than garments made in non-European countries (6.88
229 vs. 7.51 ng/g for BPA, $p < 0.05$; 0.35 vs. 1.41 ng/g for BPF, $p < 0.05$; 1.02 vs. 1.05 ng/g for BPS).
230 The current results were compared with data found in the scientific literature (Table 4). Higher
231 detection rates (%) for BPA, BPF, and BPS were noted in our study, but concentration values were
232 generally lower than elsewhere. BPS presents similar levels in new clothes commercialized in the
233 United States. Generally, the higher values of BPs were determined in samples from China (Wang
234 et al., 2019).

235

236 *3.2. Exposure assessment and risk characterization*

237 Human exposure was estimated for pregnant women, newborns, and toddlers. Risk
238 assessment considered all the daily worn clothing; hence, the result was reported as the sum of all
239 the analyzed clothing pieces and their contribution percentage. The estimated dermal exposure is
240 summarized in Table 5. Higher dermal exposure values were observed for BPA, since it also
241 showed the highest concentrations in clothing. Furthermore, exposure of pregnant women
242 ($1.24 \cdot 10^{-9}$ mg/kg/day for BPA) was higher than those of the other studied groups ($4.94 \cdot 10^{-10}$
243 mg/kg/day in newborns and $1.06 \cdot 10^{-9}$ mg/kg/day in toddlers). On the other hand, it is important to
244 remark that toddlers present a larger skin-area-to-body-weight ratio, which might lead to a greater

245 dermal exposure risk to BPA. The use of BPA has been restricted in some food-related products
246 (Huang et al., 2018). Therefore, human exposure to this compound via dermal contact with clothes
247 may become more relevant over the years. However, compared with data from different Spanish
248 populations, dermal contact with clothes is 4-5 orders lower than dietary exposure to BPA.
249 Martínez et al. (2021) reconstructed the exposure to BPA during pregnancy and estimated its intake
250 through food consumption in $7.2 \cdot 10^{-5}$, $6.9 \cdot 10^{-5}$, and $3.8 \cdot 10^{-5}$ mg/kg/day in the first, second, and
251 third trimesters, respectively. In turn, González et al. (2020a) performed a biomonitoring study in
252 an adult Spanish cohort population who followed a diet based on high consumption of canned
253 food, which had previously been shown to contain high levels of BPA (González et al. 2020b).
254 After two days, the control group showed a BPA dietary intake of $2.7 \cdot 10^{-5}$ mg/kg bw/day, 4 times
255 lower than the exposed group. Even for participants who did not follow a diet rich in canned food
256 products, the contribution of food consumption is notably larger than dermal exposure to BPA.

257 The non-carcinogenic risk was evaluated by calculating the HQ. Results are only estimated
258 for BPA, as this is the only analog for which an established RfD value has been established by the
259 US EPA. Figure 2 depicts the results of the risk assessment under a worst-case scenario, that is to
260 say, considering the maximum concentrations. Because pregnant women's clothes showed higher
261 BPA concentrations, exposure to BPA was estimated to be higher in women than in babies. It
262 must be taken into account that exposure to specific pollutants is hazardous to human health when
263 the HQ value exceeds the unity ($HQ > 1$).

264 The EU Scientific Committee on Consumer Safety (SCCS) concluded that there is no risk
265 for systemic health effects due to the use of clothing articles (European Commission, 2021).
266 Notwithstanding, in that Opinion, the SCCS also highlighted that the assessment was based only
267 on one source of BPA (*i.e.*, textiles) and did not consider the contribution of other potential
268 sources. This is a very important issue, as exposure to BPA occurs through different routes: oral,
269 inhalation, and dermal route as leach-out products (Khan et al., 2021). Furthermore, clothes may

270 contain a wide range of chemical additives with the potential to cause adverse health effects.
271 Traces of other toxicants, such as aromatic amines or polychlorinated biphenyls (PCBs), were
272 recently detected in the same textile pieces (Herrero et al., 2022a; Souza et al., 2023). When
273 performing a health risk assessment, it is essential to consider the co-occurrence of chemicals in
274 the sources of exposure, as well as the potential synergetic effects among them. This issue can be
275 tackled by estimating the aggregated exposure to all these chemicals through clothing.

276 The current study focused on determining BP concentrations in new clothes but not used
277 garments. The availability and levels of BP in used clothes are different. Consequently, human
278 exposure may be altered (Xue et al., 2017; Wang et al., 2019). During laundering, the cross-
279 contamination of BPA may occur due to homogenizing the pollutants together with all used clothes
280 (Wang et al., 2019). However, washing has been pointed out as a safe and simple practice for
281 consumers, as it may be very beneficial to reduce the content of chemicals in clothes (Herrero et
282 al., 2022b).

283

284 **4. Conclusions**

285 It is well known that early-life exposure to BPA and some analogs are associated with
286 various adverse health effects. However, more data are still necessary to establish the occurrence
287 of these EDCs in clothing, mainly for sensitive groups of populations such as pregnant women,
288 newborns, and toddlers. The current results show significant evidence that clothing is a relevant
289 source of exposure to BPA, with a 100% of detection rate in all analyzed pieces, mainly those
290 made of synthetic fibers and for pregnant women. Although preliminary calculations suggest that
291 it could be a minor route, dermal exposure to BPA still needs to be addressed compared to other
292 exposure pathways. However, the trend for the coming years is that human exposure to other BPs
293 analogs via dermal contact might become more relevant for public health. BPA has already been

294 banned in other sectors, such as in food-related products and baby products. Therefore, as a public
295 health precautionary principle, BPA should also be regulated in the textile industry.

296

297 **5. Declarations**

298 *Credit author statement*

299 Marta Herrero: Conceptualization; Formal analysis; Investigation; Methodology; Resources;
300 Writing – original draft.

301 Marília Cristina Oliveira Souza: Conceptualization; Writing – original draft.

302 Neus González: Conceptualization; Writing – review & editing.

303 Montse Marquès: Conceptualization; Writing – review & editing.

304 Fernando Barbosa: Writing – review & editing.

305 José L. Domingo: Writing – review & editing.

306 Martí Nadal: Conceptualization; Funding acquisition; Project administration; Writing – review &
307 editing.

308 Joaquim Rovira: Conceptualization; Writing – review & editing.

309

310 *Conflict and/or competing interest*

311 The authors declare that they do not have known competing financial interests or personal
312 relationships that could have appeared to influence the study here reported.

313

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317

318 *Ethics approval and consent to participate*

319 Not applicable

320

321 *Consent for publication*

322 Not applicable.

323

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Table 1. Parameters used to assess dermal exposure.

Variable	Description	Value	Reference
F_{cloth}	Weight fraction of substance in garments	Cloth specific mg/mg	Present Study
d_{cloth}	Clothing density	Cloth specific mg/cm ²	Herrero et al., 2022b
A_{skin}	Pregnancy women t-shirt (trunk+arms)	8910 cm ²	U.S. EPA, 2011
	Pregnancy Troussers_Jeans_Leggings (legs)	5980 cm ²	
	Pregnancy Band of Trouser (trunk/2)	3270 cm ²	
	Pregnancy Troussers_Jeans_Leggings + Band (legs+trunk/2)	9250 cm ²	
	Pregnancy Bra (Bosom)	2594 cm ²	
	Pregnancy underwear without brand (Genitals and buttocks)	1469 cm ²	
	Pregnancy underwear with brand (Genitals and buttocks +trunk/2)	4739 cm ²	
	Baby Pyjamas (Trunk+Arms+Legs+Feet)	2778 cm ²	
	Baby Bodysuits (trunk+arms)	1795 cm ²	
	Baby socks (Feet)	235 cm ²	
	Child's Pyjamas (Trunk+arms+legs)	4355 cm ²	
	Underwear (Genitals)	383 cm ²	
	Dresses (Trunk+arms+1/2legs)	3665 cm ²	
	T-shirt (trunk+arms)	2975 cm ²	
	Trousser/Jeans/leggings (Legs)	5980 cm ²	
$F_{contact}$	Fraction of contact area for skin	1	Bundesinstitut für Risikobewertung, 2013
F_{pen}	Fraction of penetration inside the body	0.01	
F_{mig}	Fraction of substance migrating to skin	0.005	
$T_{contact}$	Contact duration between skin-textile	0.33 (8h/24h)	Assumed
		0.67 (16h/24h) 1 (24h)	
N	Mean number of events per day	1/d	Assumed
BW	Adult Female	76.9 kg	Martínez et al., 2017
	Birth to < 12 month	7.31kg	Sobradillo et al., 2000

Table 2. Levels of BPs (in ng/g) in clothing commercialized in Spain (n=120)

	LOD ¹	DR ² (%)	Mean	SD ³	Minimum	Median	95 th percentile	Maximum
Bisphenol A	0.59	100	64.2	529	0.69	7.43	76.1	5872
Bisphenol B	0.04	13	0.99	5.27	< LOD	< LOD	5.43	44.1
Bisphenol F	0.69	73	96.0	1022	< LOD	1.01	12.9	11333
Bisphenol S	0.12	94	15.6	104	< LOD	1.04	14.2	981

¹LOD: Limit of detection; ²DR: Detection rate (%); ³SD: Standard deviation.

Table 3. Concentrations of bisphenols (ng/g) determined in different fibers of clothes, including synthetic and natural fibers.

		n	DR ¹ (%)	Mean	SD ²	Minimum	Median	95 th	Maximum
Bisphenol A	Cotton	63	100	15.7	28.2	0.69	7.07	55.5	195
	Elastane	41	100	15.5	27.9	0.86	6.95	50.1	146
	Polyester	8	100	772	2062	2.92	28.9	3878	5872
	Polyamide	11	100	9.54	6.76	1.97	8.60	20.4	24.9
Bisphenol F	Cotton	63	81	5.50	22.1	< LOD	0.98	10.2	171
	Elastane	41	73	278	1770	< LOD	1.51	5.45	11333
	Polyester	8	88	2.28	1.98	< LOD	1.56	5.34	5.47
	Polyamide	11	64	2.37	4.53	< LOD	0.29	11.3	13.6
Bisphenol S	Cotton	63	97	2.51	4.67	< LOD	0.96	12.0	28.4
	Elastane	41	98	2.45	3.25	< LOD	1.10	10.2	14.5
	Polyester	8	100	79.5	217	0.19	2.38	404	618
	Polyamide	11	64	92.9	295	< LOD	0.15	507	981

The median of BPB was lower than LOD.

¹DR: Detection rate; ²SD: Standard Deviation.

No significant differences were observed among groups ($p>0.05$).

Table 4. A summary of BPs levels in clothing found in the scientific literature.

Bisphenols	Values	This study New clothes (n=123)	Freire et al. (2019) Socks (n=32)	Wang et al. (2019) New clothes (n=44)	Xue et al. (2017) New clothes (n=77)
	Marketing country	Spain	Spain	China	USA
	DR (%)	100	91	98	82
BPA	Median	7.43	20.5	17.7	10.7
	Range	0.69–5872	<0.70 – 3736	<3.30–1823	<2.21–13300
	DR (%)	94	-	29	53
BPS	Median	1.04	-	12.3	1.02
	Range	<0.12–981	-	<0.53–536	<0.74–394
	DR (%)	73	-	-	5.2
BPF	Median	1.01	-	-	0.32
	Range	<0.69–11333	-	-	<14.7–194

Concentrations are given in ng/g.

DR: Detection rate.

Table 5. Exposure assessment to BPSs through clothing for pregnant women, newborns and toddlers.

		Bisphenol A		Bisphenol B		Bisphenol F		Bisphenol S	
		Derma Exposure per item (%)	Total Derma Exposure (mg/kg/day)	Derma Exposure per item (%)	Total Derma Exposure (mg/kg/day)	Derma Exposure per item (%)	Total Derma Exposure (mg/kg/day)	Derma Exposure per item (%)	Total Derma Exposure (mg/kg/day)
Pregnant women	T-shirts	10%		22%		2%		12%	
	Jeans/leggings	64%	1.24E-09	31%	1.39E-12	30%	2.24E-10	15%	1.56E-10
	Bras	12%		22%		26%		17%	
	Panties	14%		26%		42%		56%	
Newborns (<12 months)	Pyjamas	35%		38%		68%		83%	
	Bodies	13%	4.94E-10	24%	1.49E-12	22%	9.93E-11	13%	1.07E-10
	Socks	52%		38%		10%		4%	
Toddlers (12-36months)	Pyjamas	27%		0.4%		33%		6%	
	Underwear	34%		0.3%		3%		12%	
	Dresses	13%	1.06E-09	98%	8.85E-12	59%	2.05E-10	6%	1.87E-10
	T-Shirt	12%		0.4%		3%		19%	
	Trousers	13%		0.5%		3%		56%	

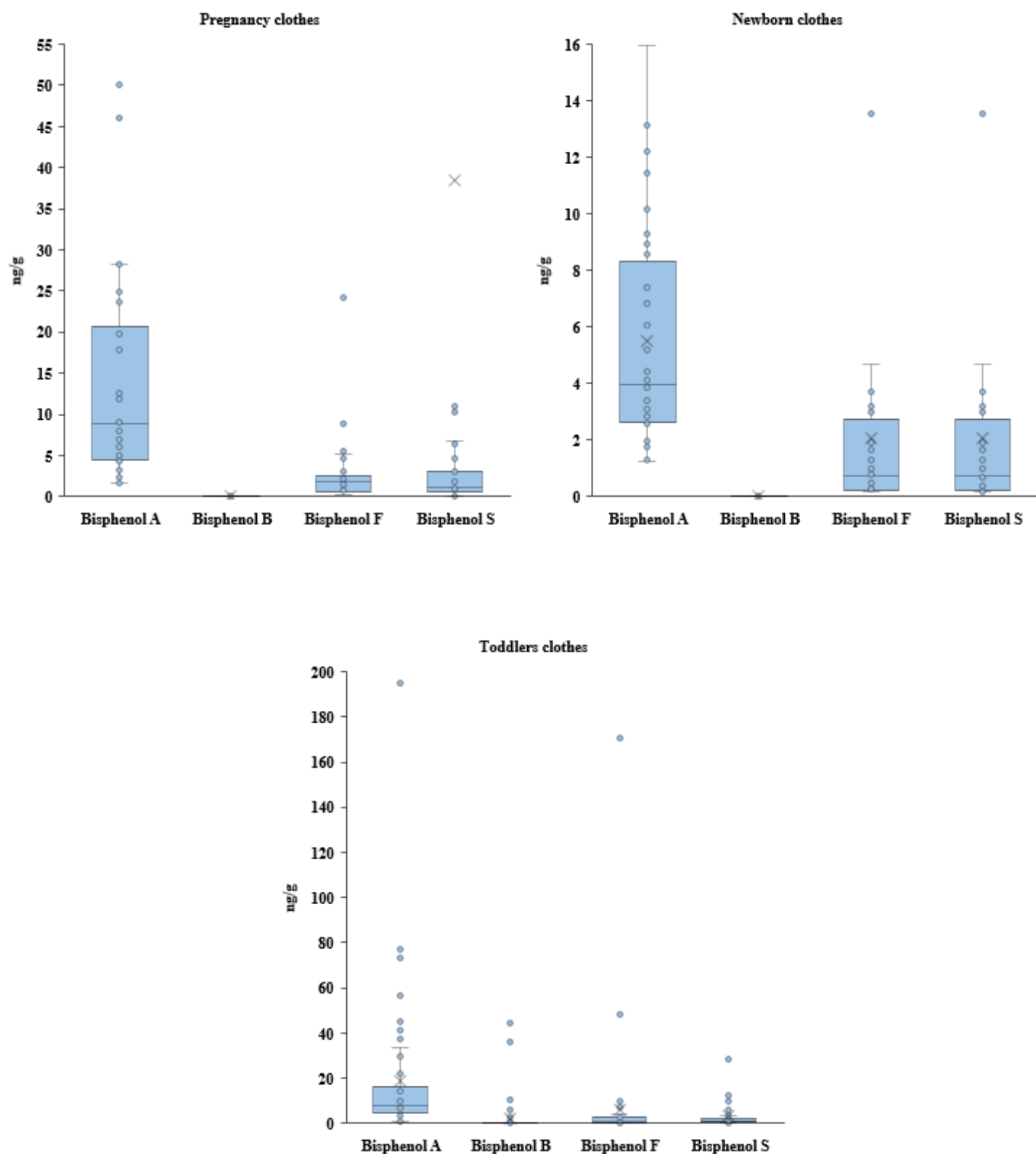


Figure 1. Concentrations of bisphenols in clothes for pregnant women, newborns and toddlers. Values are expressed as median (ng/g).

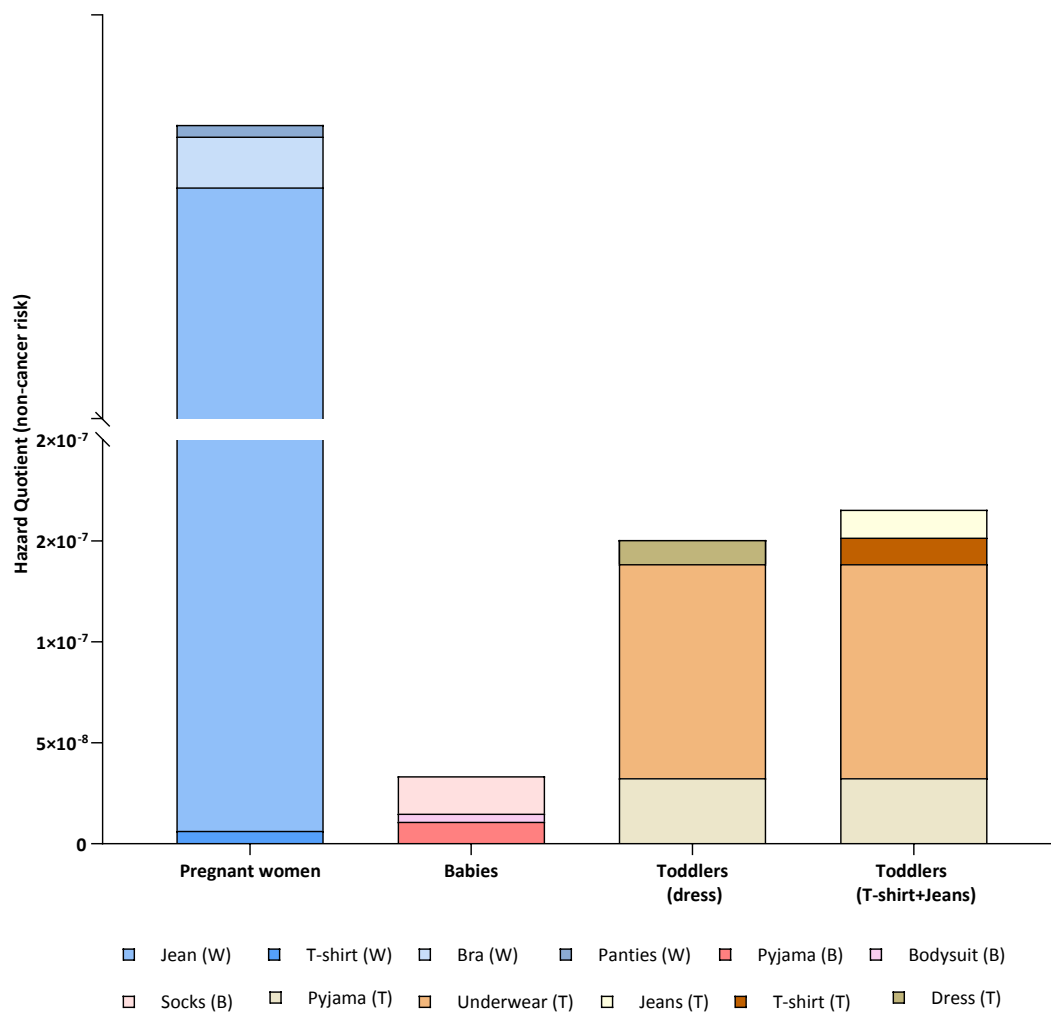


Figure 2. Hazard Quotient (non-carcinogenic risk) of bisphenol A in the upper-bound scenario (maximum concentrations) for pregnant women (W), babies (B) aged <12 months, and toddlers (T) aged 12–36 months.



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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Author Contributions Statement

Marta Herrero: Conceptualization; Formal analysis; Investigation; Methodology; Resources; Writing – original draft.

Marília Cristina Oliveira Souza: Conceptualization; Writing – original draft.

Neus González: Conceptualization; Writing – review & editing.

Montse Marquès: Conceptualization; Writing – review & editing.

Fernando Barbosa: Writing – review & editing.

José L. Domingo: Writing – review & editing.

Martí Nadal: Conceptualization; Funding acquisition; Project administration; Writing – review & editing.

Joaquim Rovira: Conceptualization; Writing – review & editing.