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# Exposure to select phthalates and phenols through use of personal care products among Californian adults and their children

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ABSTRACT

*Introduction:* Certain phenols and phthalates are used in many consumer products including personal care products (PCPs).
*Aims:* We aimed to study the associations between the use of PCPs and urinary concentrations of biomarkers of select phenols and phthalates among Californian adults and their children. As an additional aim we compared phenols and phthalate metabolites concentrations measured in adults and children urine samples collected the same day.
*Methods:* Our study relied on a subsample of 90 adult–child pairs participating in the Study of Use of Products and Exposure Related Behavior (SUPERB). Each adult and child provided one to two urine samples in which we measured concentrations of selected phenols and phthalate metabolites. We computed Spearman correlation coefficients to compare concentrations measured in adults and children urine samples collected the same day. We used adjusted linear and Tobit regression models to study the associations between the use of PCPs in the past 24 h and biomarker concentrations.
*Results:* Benzophenone-3 and parabens concentrations were higher in adults compared to their children. Conversely children had higher mono-*n*-butyl phthalate and mono-isobutyl phthalate concentrations. No significant difference was observed for the other compounds. The total number of different PCPs used was positively associated with urinary concentrations of methyl, propyl and butyl parabens and the main metabolite of diethyl phthalate in adults. Among children, the use of a few specific products including liquid soap, hair care products and sunscreen was positively associated with urinary concentrations of some phenols or phthalate metabolites.
*Discussion:* These results strengthen the body of evidence suggesting that use of PCPs is an important source of exposure to parabens and diethyl phthalate in adults and provide data on exposure to selected phenols and phthalates through use of PCPs in children.

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## 1. Introduction

Phenols and phthalates are man-made chemicals with high exposure prevalence in the general US population (Centers for Disease Control and Prevention, 2014). Epidemiological studies have reported associations between exposure to some phenols and phthalates and several health outcomes including neurodevelopmental disorders, growth, reproductive health and respiratory health (Braun et al., 2013a; Hauser and Calafat, 2005; Rochester, 2013). Phenols and phthalates are used in food packaging, manufacture of polyvinyl chloride plastics, paints and varnishes as well as in a wide range of personal care products (PCPs). In PCPs, they are used as plasticizers and fixatives in fragrances (e.g., diethyl phthalate (DEP)), antibacterial agents (triclosan) and preservatives (parabens), or sun blockers (benzophenone-3) (Dodson et al., 2012; Guo and Kannan, 2013). The number of PCPs used in the past 24–48 h has been associated with increased urinary concentrations of monoethyl phthalate (MEP), the main metabolite of DEP (Berman et al., 2009; Braun et al., 2013b; Just et al., 2010; Parlett et al., 2013; Romero-Franco et al., 2011) and with methyl, propyl and butyl parabens in adults (Braun et al., 2013b). Data were sparse in children and toddlers (Lewis et al., 2013; Sathyanarayana et al., 2008; Watkins et al., 2014) and to our knowledge, no study has explored the relationship between PCP use in the past 24–48 h and children's urinary concentrations of phenols.

*Abbreviations:* CI, confidence interval; DEP, diethyl phthalate; MBP, mono-*n*-butyl phthalate; MEP, monoethyl phthalate; MiBP, mono-isobutyl phthalate; PCP, personal care products

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Our aim was to study the relationship between the use of PCPs in the previous 24 h and urinary concentrations of phthalate metabolites and phenols in children and their parents. A further aim was to examine the within subject correlation between concentrations measured in urine samples collected one year apart.

## 2. Materials and methods

### 2.1. Study population

Participants were a subset of 90 adult–child pairs from the Study of Use of Products and Exposure-Related Behavior (SUPERB), which aimed at investigating human behaviors that could influence exposure to environmental pollutants. Briefly, in 2005–2007 SUPERB study enrolled one parent and one child of 499 Northern California families with a child born between 2000 and 2005. Families were identified and randomly selected through birth certificate records for 22 counties in the greater Sacramento, San Francisco Bay Area and surrounding areas (see Hertz-Picciotto et al. (2010) for details).

The SUPERB study protocol has been approved by the Institutional Review Board at the University of California, Davis (UC Davis). Informed consent for participation was obtained before data or specimen collection. The involvement of the Centers for Disease Control and Prevention (CDC) did not constitute engagement in human subject research.

### 2.2. Urine collection

Among the 90 parent–child pairs enrolled, 90 adults and 83 children provided a spot urine sample between December 2007 and November 2009. Participants were asked to collect an end-of-day spot urine sample a day before a study visit. Both adults and children used a specimen collection "hat" (Commode Specimen Collector, Fisher Scientific P/N 22-363-149) placed under the toilet seat and a standard polypropylene urine cup to store the urine overnight in a refrigerator. The day following collection, urine samples were transported on ice packs to UC Davis, aliquoted and frozen at −80 °C. If no urine sample was collected in the evening, one was collected during the study visit. Another urine sample was collected using the same protocol one year later for 42 parents and 41 children (the second urine samples were collected between May and December 2009).

### 2.3. Use of PCPs

During the study visit, the enrolled parents completed a detailed questionnaire for themselves and their child about the use of different PCPs in the 24 h preceding the urine collection. Therefore, all questionnaire data pertain to the 24 h prior to when the urine sample was collected. We studied each PCP individually and also computed scores corresponding to the sum of PCPs and the sum of scented PCPs used per individual within the 24 h collection window.

Toothpastes are suggested to be a contributing source of human exposures to triclosan (Koch et al., 2014). As nearly all the population ($\geq$98%) reported using this product in the past 24 h, we focused on discriminating between product brands used. In the US market, Colgate Total® is the only FDA-approved toothpaste containing triclosan. The questionnaire did not discriminate between users of Colgate Total® and users of other Colgate® toothpastes. For this reason, we compared triclosan levels of Colgate® toothpaste users against users of all other brands.

### 2.4. Urinary concentrations of phenols and phthalate metabolites

Eleven phthalate metabolites and eight phenols (free plus conjugated forms) were quantified at the CDC in Atlanta, GA, USA using previously described methods (Silva et al., 2007; Ye et al., 2006). However, for this study, we restricted our analysis to the metabolites of phenols and phthalates likely to be found in PCPs, namely DEP, di-*n*-butyl phthalate, di-isobutyl phthalate, benzophenone-3, triclosan and three parabens (methyl, propyl, butyl (as the sum of *n*-plus iso-isomers)). MEP (metabolite of DEP) concentrations have been corrected [multiplied by 0.66] because the analytical standards used at the time of the analyses were of inadequate purity (Centers for Disease Control and Prevention, 2012). Urinary creatinine concentration was measured at CDC by an enzymatic reaction using a Roche Hitachi 912 chemistry analyzer (Roche Hitachi, Basel, Switzerland).

### 2.5. Statistical analysis

In order to limit the influence of extreme values, biomarker concentrations were ln-transformed. Concentrations below the limit of detection (LOD) for which a signal was detected were reported as measured (Harley et al., 2013). We replaced any concentrations that were below the LOD, and had no signal detected, by the lowest instrumental reading value divided by square root of 2.

We used graphical tools and Spearman correlation coefficients to compare concentrations in adults' and children's urine samples collected the same day. We computed Spearman correlations and Cohen's kappa coefficients (based on tertiles) to compare concentrations measured in samples collected 1 year apart (comparisons between visits 1 and 2) for both adults and children. We used the following cutoffs: $<0.4$, weak; 0.4–0.6, moderate; and $>0.6$, good, to classify the strength of the correlations (Philippat et al., 2013). To enhance comparability we computed a *Z*-score for each biomarker concentration as follow: *Z*-score for a participant $i$=[concentration for subject $i$−mean of the population]/Standard Deviation (SD) of the population. We then study the associations between each biomarker concentration (*Z*-score) and reports of PCP use in the previous 24 h, at the two study visits using an adjusted linear mixed effect model. For triclosan and butyl paraben, for which more than 10% of the urinary concentrations were not detectable, we used a Tobit regression model instead of the linear regression model.

Adults and children were studied separately. Our models were adjusted for participant sex, age, education level and race of the adult, as well as creatinine concentration, a marker of urine dilution. Because the same chemical might be used in different PCPs, we additionally adjusted our models for the total number of other PCPs used, not counting the one being examined (Braun et al., 2013b). We reported results as the ratio of metabolite concentrations in exposed versus unexposed subjects (exponential of the beta coefficient).

## 3. Results

### 3.1. Study population

Adult participants were on average 38.5 years old (SD, 6.5 years) at the first urine sampling, mostly female (90%) and one third were either Hispanic or non-white race; 72% of them had at least an associate or bachelor degree. Children were on average 5.6 years old (SD, 1.4 years) at the first urine collection; 49% of them were females (Table 1).

Adults used more PCPs than their children; with medians of 9

**Table 1**
Characteristics of the study population (SUPERB study, 2007–2009).

| | *N* | % |
|---|---|---|
| **Adult (*n*=90)** | | |
| Sex | | |
| Female | 81 | 90 |
| Male | 9 | 10 |
| **Education** | | |
| High school, some college but no degree | 27 | 28 |
| Associate or bachelor degree | 41 | 46 |
| Post-graduate degree | 23 | 26 |
| Missing | 1 | 1 |
| **Race** | | |
| White (non-Hispanic) | 60 | 67 |
| Hispanic (any) | 13 | 14 |
| African American | 2 | 2 |
| Asian | 7 | 8 |
| Mixed | 3 | 3 |
| Other | 4 | 4 |
| Missing | 1 | 1 |
| **Marital status** | | |
| Married | 89 | 99 |
| Missing | 1 | 1 |
| **Age (years)**[a] | | |
| 24–34 | 18 | 20 |
| 35–54 | 70 | 78 |
| 55–62 | 2 | 2 |
| **Season of sampling**[a] | | |
| November–February | 33 | 37 |
| March–June | 30 | 33 |
| July–October | 27 | 30 |
| **Hour of sampling**[a] | | |
| ≤ 16.59 | 5 | 6 |
| 17.00–20.59 | 24 | 27 |
| 21.00–24.00 | 61 | 68 |
| **Child (*n*=83)** | | |
| **Sex** | | |
| Female | 41 | 49 |
| Male | 42 | 51 |
| **Age (years)**[a] | | |
| 3–3.9 | 11 | 13 |
| 4–5.9 | 38 | 46 |
| 6–7.9 | 29 | 35 |
| ≥ 7.9 | 5 | 6 |
| **Season of sampling**[a] | | |
| November–February | 28 | 34 |
| March–June | 31 | 37 |
| July–October | 24 | 29 |
| **Hour of sampling**[a] | | |
| ≤ 16.59 | 8 | 11 |
| 17.00–20.59 | 51 | 60 |
| 21.00–24.00 | 24 | 29 |

[a] At the 1st study visit.

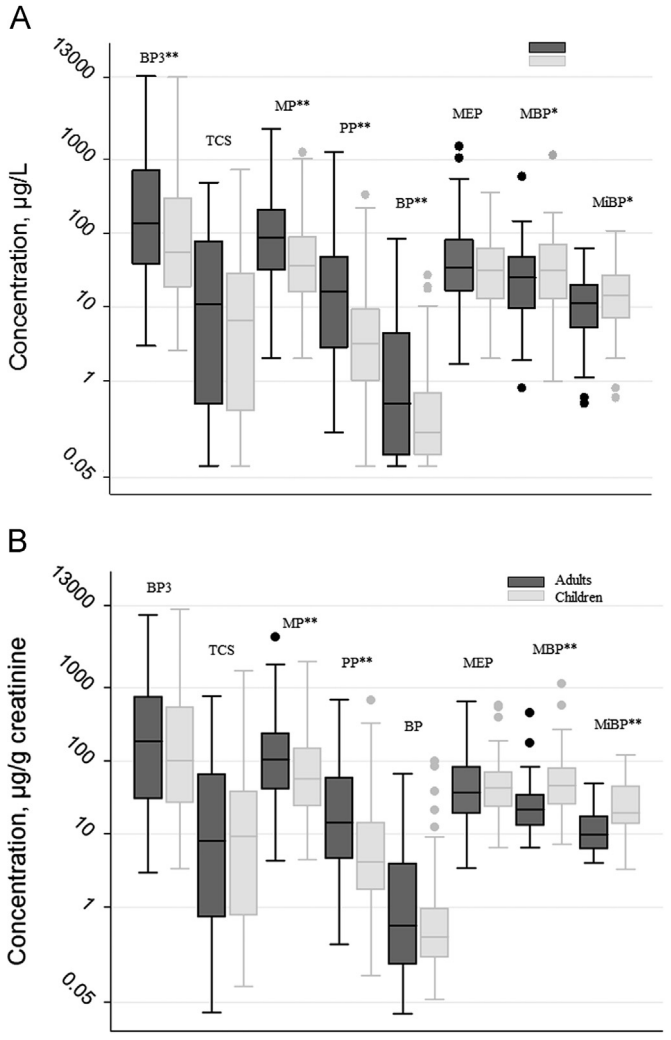


**Fig. 1.** Urinary concentrations of phenols and phthalate metabolites uncorrected (A) and corrected (B) for creatinine among adults and their children (first visit of the SUPERB study 2007–2009, $n=81$[a]). [a]Restricted to adult–child pairs with urine sample for both the adults and the children. Two adults–child pairs were excluded from this analysis because the parent and the child collected their urine sample several days apart. Abbreviations: BP: butyl paraben, BP3: benzophenone-3, MBP: mono-*n*-butyl phthalate, MEP: monoethyl phthalate, MiBP: mono-isobutyl phthalate, MP: methyl paraben, PP: propyl paraben, TCS: triclosan. $^{**}p$-Values for Mann–Whitney test ≤ 0.05, $^{*}p$-Values for Mann–Whitney test ≤ 0.10.

(5–95th percentiles: 4–13) and 4 PCPs (5–95th percentiles: 2–7), respectively. In adults the most frequently used PCPs at the first and second study visits were toothpaste (100%), liquid soap (88%) and deodorant (74–76%, depending on the visit), compared with toothpaste (98%), liquid soap (86–88%) and shampoo (34–37%) in children (Appendix, Fig. A1). About 40% of the adults (39% and 43% at the first and second visit, respectively) and 30% of the children (30% and 35% at the first and second visit, respectively) reported using Colgate® toothpaste.

### 3.2. Phenol and phthalate metabolite concentrations

Except for triclosan and butyl paraben, biomarker concentrations were below the LOD in fewer than 10% of the urine samples (Appendix, Table A1). In adults, the highest concentration among phthalate metabolites was for MEP followed by mono-*n*-butyl phthalate (MBP) and mono-iso-butyl phthalate (MiBP). In children, the highest concentration among phthalate metabolites was for MBP, followed by MEP and MiBP. Among phenols, the highest concentrations were observed for benzophenone-3 and methyl paraben (Fig. 1, Appendix, Table A1). We observed good correlation between methyl and propyl parabens ($\rho=0.84$ and 0.66 in adults and children, respectively). Lower correlation was observed between these two parabens and butyl paraben (Appendix, Table A2). Correlation between MiBP and MBP was 0.48 in adults and 0.63 in children. MEP was not strongly associated with any other compounds ($\rho<0.4$, in both adults and children, Appendix, Table A2).

We observed higher creatinine concentrations in adults (median of 114 mg/dL and 128 mg/dL in the 1st and 2nd visits, respectively) compared to their children (median of 74 mg/dL and 60 mg/dL, Appendix, Table A1). Such finding has been reported previously and might reflect difference in muscle mass between adults and children rather than in urine dilution (Barr et al., 2005). For this reason, to compare adult and child urinary concentrations, we focused on the biomarker concentrations uncorrected for

**Table 2**
Adjusted associations between the use of PCPs and phenol and phthalate metabolite urinary concentrations in adults ($n$=90, SUPERB study, 1st and 2nd visit, 2007–2009).

| | Benzophenone-3 | | Triclosan | | Methyl paraben | | Propyl paraben | | Butyl paraben | | Monoethyl phthalate | | Mono-*n*-butyl phthalate | | Mono-isobutyl phthalate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI | Ratio | 95% CI |
| **Number of PCPs used** | | | | | | | | | | | | | | | | |
| 3–7[a] | | | | | | | | | | | | | | | | |
| 7–10 | 1.05 | [0.71; 1.56] | 1.11 | [0.72; 1.72] | 1.52 | [1.06; 2.18] | 1.47 | [1.01; 2.14] | 1.88 | [1.25; 2.85] | 1.21 | [0.87; 1.68] | 0.66 | [0.48; 0.89] | 0.91 | [0.66; 1.25] |
| 11–15 | 1.07 | [0.69; 1.66] | 1.16 | [0.68; 1.98] | 2.21 | [1.48; 3.30] | 2.00 | [1.31; 3.04] | 1.88 | [1.19; 2.97] | 1.66 | [1.15; 2.40] | 0.59 | [0.42; 0.82] | 0.79 | [0.56; 1.11] |
| **Number of scented PCPs used** | | | | | | | | | | | | | | | | |
| $\leq 4$[a] | | | | | | | | | | | | | | | | |
| 5–7 | 1.12 | [0.76; 1.63] | 0.94 | [0.62; 1.40] | 1.09 | [0.77; 1.56] | 1.01 | [0.71; 1.44] | 1.49 | [1.02; 2.19] | 1.02 | [0.74; 1.40] | 0.82 | [0.60; 1.12] | 0.95 | [0.70; 1.30] |
| 7–13 | 1.25 | [0.81; 1.93] | 1.25 | [0.76; 2.06] | 1.75 | [1.16; 2.63] | 1.70 | [1.11; 2.59] | 1.36 | [0.86; 2.15] | 1.18 | [0.81; 1.72] | 0.77 | [0.54; 1.09] | 0.82 | [0.58; 1.17] |
| **Deodorant** | 1.08 | [0.72; 1.63] | 0.89 | [0.56; 1.42] | 1.28 | [0.88; 1.85] | 1.17 | [0.80; 1.72] | 1.53 | [1.00; 2.34] | 1.21 | [0.86; 1.70] | 0.83 | [0.61; 1.15] | 1.22 | [0.89; 1.68] |
| **Shampoo** | 0.80 | [0.57; 1.14] | 1.11 | [0.74; 1.67] | 1.02 | [0.74; 1.40] | 0.95 | [0.69; 1.33] | 0.83 | [0.58; 1.20] | 0.89 | [0.66; 1.19] | 1.00 | [0.76; 1.32] | 0.94 | [0.71; 1.24] |
| **Other haircare products**[b] | 0.87 | [0.61; 1.24] | 1.12 | [0.76; 1.65] | 1.38 | [1.00; 1.90] | 1.30 | [0.93; 1.81] | 1.04 | [0.72; 1.51] | 0.90 | [0.67; 1.20] | 0.93 | [0.70; 1.23] | 0.93 | [0.70; 1.23] |
| **Cologne/perfume** | 0.75 | [0.52; 1.10] | 1.05 | [0.67; 1.63] | 1.25 | [0.88; 1.77] | 1.34 | [0.93; 1.92] | 1.34 | [0.90; 2.01] | 1.36 | [0.99; 1.87] | 0.87 | [0.65; 1.18] | 0.84 | [0.62; 1.14] |
| **Facial cleansing** | 1.09 | [0.78; 1.53] | 0.91 | [0.63; 1.31] | 1.33 | [0.98; 1.81] | 1.57 | [1.15; 2.15] | 1.30 | [0.88; 1.92] | 1.06 | [0.80; 1.41] | 1.07 | [0.82; 1.41] | 0.98 | [0.74; 1.29] |
| **Bar soap** | 0.86 | [0.62; 1.20] | 0.80 | [0.55; 1.16] | 0.76 | [0.57; 1.03] | 0.66 | [0.49; 0.90] | 0.67 | [0.48; 0.95] | 0.83 | [0.63; 1.10] | 0.95 | [0.73; 1.24] | 0.97 | [0.74; 1.27] |
| **Liquid soap** | 1.02 | [0.63; 1.65] | 1.25 | [0.74; 2.10] | 0.91 | [0.59; 1.40] | 0.84 | [0.54; 1.32] | 1.04 | [0.62; 1.75] | 1.15 | [0.77; 1.72] | 0.89 | [0.61; 1.30] | 0.98 | [0.67; 1.44] |
| **Hand sanitizer** | 1.31 | [0.87; 1.99] | 0.77 | [0.47; 1.28] | 0.96 | [0.66; 1.39] | 1.07 | [0.72; 1.60] | 1.20 | [0.78; 1.87] | 1.01 | [0.71; 1.44] | 1.02 | [0.74; 1.40] | 1.16 | [0.85; 1.60] |
| **Hand/body lotion** | 1.13 | [0.77; 1.66] | 1.23 | [0.79; 1.91] | 1.07 | [0.76; 1.51] | 1.01 | [0.70; 1.45] | 0.81 | [0.54; 1.21] | 1.17 | [0.85; 1.61] | 0.93 | [0.69; 1.26] | 0.85 | [0.63; 1.16] |
| **Other face lotion or cream** | 1.04 | [0.73; 1.50] | 0.80 | [0.54; 1.20] | 0.81 | [0.59; 1.12] | 0.73 | [0.52; 1.01] | 0.88 | [0.61; 1.27] | 1.01 | [0.75; 1.37] | 0.78 | [0.59; 1.03] | 0.85 | [0.64; 1.13] |
| **Mouthwash** | 0.68 | [0.43; 1.07] | 1.15 | [0.69; 1.91] | 1.05 | [0.69; 1.58] | 0.96 | [0.63; 1.48] | 1.83 | [1.15; 2.90] | 1.34 | [0.92; 1.96] | 0.85 | [0.60; 1.22] | 0.71 | [0.50; 1.01] |
| **Shaving cream** | 1.85 | [1.08; 3.16] | 1.79 | [0.93; 3.42] | 1.22 | [0.74; 2.01] | 1.52 | [0.90; 2.58] | 0.69 | [037; 1.28] | 1.24 | [0.78; 1.97] | 1.21 | [0.80; 1.84] | 1.03 | [0.67; 1.57] |
| **Powder (on face, feet or body)** | 0.87 | [0.52; 1.48] | 0.80 | [0.41; 1.57] | 1.06 | [0.66; 1.72] | 1.25 | [0.75; 2.09] | 1.45 | [0.83; 2.53] | 1.29 | [0.83; 2.01] | 1.12 | [0.75; 1.66] | 1.26 | [0.85; 1.88] |
| **Colored cosmetics**[c] | 1.08 | [0.75; 1.56] | 0.91 | [0.60; 1.37] | 1.09 | [0.78; 1.51] | 1.32 | [0.94; 1.86] | 1.66 | [1.14; 2.41] | 0.91 | [0.67; 1.23] | 0.85 | [0.64; 1.13] | 0.94 | [0.71; 1.26] |
| **Chapstick or lipbalm** | 1.05 | [0.75; 1.46] | 1.11 | [0.78; 1.56] | 1.09 | [0.81; 1.47] | 1.13 | [0.83; 1.53] | 1.06 | [0.76; 1.47] | 1.33 | [1.02; 1.74] | 0.94 | [0.72; 1.23] | 0.96 | [0.73; 1.26] |
| **Suntan lotion** | 2.21 | [1.47; 3.32] | 1.15 | [0.73; 1.80] | 1.49 | [1.03; 2.17] | 1.31 | [0.89; 1.93] | 1.16 | [0.75; 1.79] | 1.11 | [0.78; 1.56] | 0.93 | [0.67; 1.31] | 1.13 | [0.80; 1.59] |

We reported the adjusted ratio of the biomarker concentrations in exposed and unexposed subjects (exponential of the beta coefficient). Our models were adjusted for participant sex, age, education level, race, creatinine concentration and the total number of other personal care products used, not counting the one being examined. Analysis restricted to PCPs used by at least 5 subjects.

[a] Reference category.
[b] Includes hair conditioner, gel, spray, moose, hair bleach, relaxer, and perm.
[c] Includes foundation, blush, eye shadow, eye liner, and mascara.

creatinine (Fig. 1A). Benzophenone-3, methyl, propyl, and butyl paraben concentrations were higher in adults compared to their children, whereas concentrations of MBP and MiBP were higher in children compared to their parents. No significant difference between adults and children was observed for any other biomarkers ($p$-Values for Mann–Whitney test $\geq 0.1$, Fig. 1A). Correlations between adult and child urine concentrations were good for benzophenone-3 ($\rho=0.65$), and moderate for triclosan ($\rho=0.47$) and butyl paraben ($\rho=0.52$). We observed weak correlations ($<0.4$) for the other biomarkers (Appendix, Table A3).

### 3.3. Temporal variability

The time elapsed between the first and second visit ranged between 225 and 505 days (mean=348 days). Only 42 adults and 36 children had repeated measures of phenol and phthalate metabolite concentrations. In adults, Spearman correlation coefficients between the two measurements were good for benzophenone-3, triclosan, propyl paraben and butyl paraben, moderate for methyl paraben and MEP, and weak for the other biomarkers (concentration standardized for creatinine, Appendix, Table A4). Except for MBP, Spearman correlation coefficients observed in children were lower than those in adults. In children we observed moderate to good correlation for all phenols except butyl paraben ($\rho=0.18$) and weak correlation for the three phthalate metabolites assessed in our study (concentration standardized for creatinine, Appendix, Table A3). Except for triclosan in adults (kappa=0.5), Cohen's kappa coefficients were below 0.4 in both adults and children (Appendix, Table A4).

### 3.4. Adjusted associations between the use of PCPs and biomarker concentrations

After adjustment, adults reporting use of 7–15 PCPs in the past 24 h had on average higher urinary concentrations of methyl, propyl and butyl paraben than adults using fewer than 7 PCPs. The total number of scented PCPs used was also positively associated with methyl, propyl and butyl paraben concentrations (Table 2). We observed different pattern of associations between the use of specific PCPs and each paraben. In adults, methyl paraben concentration was on average higher among users of sunscreen (ratio: 1.49; 95% confidence interval (CI): 1.03–2.17) and hair care products including hair conditioner, hair gel, hair spray, moose, hair bleach, relaxer and perm (ratio: 1.38; 95% CI: 1.00–1.90). Higher propyl paraben concentration was associated with use of facial cleaning products (ratio: 1.57; 95% CI: 1.15–2.15) while increased butyl paraben concentrations were found in those reporting use of deodorants (ratio: 1.53; 95% CI: 1.00–2.34), mouthwash (ratio: 1.83; 95% CI: 1.15–2.90), and colored cosmetics (including foundation, blush, eye shadow, eye liner, mascara, ratio: 1.66; 95% CI: 1.14–2.41). In children, the total number of PCPs used was not associated with increased paraben concentrations ($p$-Values $\geq 0.17$), although increased urinary concentrations of some parabens were associated with use of specific PCPs including sunscreen (methyl paraben) and hair care products (butyl paraben, Table 3). Lower concentrations of methyl, propyl and butyl parabens were found in users of bar soap in both adults ($p$-Values ranged between 0.009 and 0.07, Table 2) and children ($p$-Values ranged between $<0.004$ and 0.20, Table 3).

We observed higher benzophenone-3 concentration among users of sunscreen in both adults (ratio=2.21; 95% CI: 1.47–3.32) and children (ratio=3.10, 95% CI: 1.83–5.25). In adults shaving cream use was also positively associated with benzophenone-3 concentration (ratio: 1.85; 95% CI: 1.08–3.16).

In both adults and children, users of Colgate® toothpaste had on average higher urinary concentrations of triclosan compared to

**Table 3**
Adjusted associations between the use of specific PCPs and phenol and phthalate metabolite urinary concentrations among children ($n=83$, SUPERB study, 1st and 2nd study visit, 2007–2009).

| | Benzophenone-3 | | Triclosan | | Methyl paraben | | Propyl paraben | | Butyl paraben | | Monoethyl phthalate | | Mono-*n*-butyl phthalate | | Mono-isobutyl phthalate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC | Ratio | 95% IC |
| **Number of PCPs used** | | | | | | | | | | | | | | | | |
| ≤3[a] | | | | | | | | | | | | | | | | |
| 3–5 | 1.13 | [0.75; 1.70] | 0.95 | [0.61; 1.47] | 0.85 | [0.58; 1.26] | 1.07 | [0.73; 1.56] | 1.27 | [0.78; 2.06] | 0.80 | [0.55; 1.16] | 0.81 | [0.58; 1.13] | 0.79 | [0.56; 1.12] |
| 5–10 | 1.22 | [0.75; 1.98] | 0.97 | [0.57; 1.65] | 1.19 | [0.76; 1.88] | 1.36 | [0.88; 2.12] | 1.34 | [0.77; 2.32] | 1.07 | [0.69; 1.67] | 0.72 | [0.50; 1.06] | 0.86 | [0.57; 1.29] |
| **Number of scented PCPs used** | | | | | | | | | | | | | | | | |
| ≤2[a] | | | | | | | | | | | | | | | | |
| 2–3 | 0.82 | [0.53; 1.26] | 1.45 | [0.90; 2.34] | 0.75 | [0.49; 1.14] | 0.67 | [0.45; 0.99] | 0.71 | [0.42; 1.18] | 1.40 | [0.94; 2.09] | 0.74 | [0.52; 1.06] | 0.89 | [0.61; 1.28] |
| 3–8 | 1.10 | [0.72; 1.69] | 1.23 | [0.78; 1.95] | 1.10 | [0.73; 1.63] | 1.28 | [0.87; 1.87] | 1.19 | [0.74; 1.92] | 1.35 | [0.92; 1.99] | 0.96 | [0.69; 1.35] | 1.28 | [0.90; 1.83] |
| **Shampoo** | 1.26 | [0.86; 1.85] | 0.86 | [0.56; 1.32] | 0.80 | [0.56; 1.15] | 1.17 | [0.82; 1.67] | 0.97 | [0.63; 1.51] | 1.04 | [0.73; 1.50] | 0.98 | [0.73; 1.33] | 1.21 | [0.87; 1.67] |
| **Other haircare products**[b] | 0.94 | [0.61; 1.43] | 1.15 | [0.72; 1.83] | 0.86 | [0.58; 1.27] | 1.02 | [0.69; 1.51] | 1.74 | [1.09; 2.76] | 0.93 | [0.63; 1.38] | 0.93 | [0.67; 1.29] | 1.30 | [0.91; 1.85] |
| **Bar soap** | 0.61 | [0.41; 0.90] | 0.87 | [0.56; 1.37] | 0.65 | [0.45; 0.94] | 0.79 | [0.55; 1.15] | 0.49 | [0.32; 0.77] | 0.93 | [0.64; 1.35] | 1.09 | [0.79; 1.51] | 0.93 | [0.66; 1.31] |
| **Liquid soap** | 1.47 | [0.91; 2.37] | 1.23 | [0.72; 2.08] | 0.94 | [0.59; 1.49] | 0.76 | [0.49; 1.18] | 1.46 | [0.82; 2.59] | 1.65 | [1.07; 2.56] | 0.99 | [0.67; 1.46] | 1.13 | [0.75; 1.71] |
| **Hand sanitizer** | 0.71 | [0.48; 1.06] | 0.98 | [0.64; 1.51] | 1.30 | [0.89; 1.90] | 1.01 | [0.70; 1.47] | 1.21 | [0.75; 1.95] | 0.83 | [0.57; 1.19] | 0.78 | [0.56; 1.08] | 0.66 | [0.47; 0.93] |
| **Hand/body lotion** | 1.05 | [0.62; 1.76] | 0.92 | [0.53; 1.60] | 1.11 | [0.68; 1.82] | 0.97 | [0.60; 1.57] | 0.74 | [0.40; 1.37] | 0.66 | [0.41; 1.06] | 0.78 | [0.51; 1.19] | 1.01 | [0.65; 1.58] |
| **Chapstick/lipbalm** | 0.90 | [0.56; 1.44] | 1.11 | [0.67; 1.85] | 1.25 | [0.79; 1.96] | 1.10 | [0.71; 1.71] | 0.91 | [0.52; 1.60] | 0.98 | [0.64; 1.52] | 0.91 | [0.62; 1.35] | 0.93 | [0.62; 1.40] |
| **Suntan lotion** | 3.10 | [1.83; 5.25] | 1.24 | [0.68; 2.26] | 1.91 | [1.14; 3.18] | 1.39 | [0.84; 2.30] | 1.68 | [0.89; 3.18] | 0.77 | [0.47; 1.26] | 1.63 | [1.05; 2.54] | 1.40 | [0.88; 2.22] |

We reported the adjusted ratio of the biomarker concentrations in exposed and unexposed subjects (exponential of the beta coefficient). Our models were adjusted for participant sex, age, education level and race of the adult, creatinine concentration and the total number of other personal care products used, not counting the one being examined Analysis restricted to PCPs used by at least 5 subjects.

[a] Reference category.

[b] Includes hair conditioner, gel, spray and moose.

users of other toothpaste brands (ratios were 2.47 (95% CI: 1.71–3.56) and 1.87 (95% CI: 1.22–2.88) in adults and children, respectively).

Regarding phthalates, in adults the total number of PCPs used was positively associated with MEP, but negatively with MBP concentrations. We did not observe clear associations between the number of scented PCPs used and the studied phthalate biomarkers. Adults reporting using lip balm in the previous 24 h had on average higher MEP concentration (ratio: 1.33; 95% CI: 1.02–1.74); no other PCP was positively associated with phthalate metabolites in adults (Table 2). Among children the number of PCPs used was not associated with phthalate metabolite concentrations; however, users of liquid soap tended to have higher MEP urinary concentration (ratio: 1.65; 95% CI: 1.07–2.56) while sunscreen users had on average higher MBP (ratio: 1.63; 95% CI: 1.05–2.54, Table 3).

Excluding adult males ($n=9$) did not change our findings. The sample size was too low to perform a sex stratified analysis in children ($n=41$ females and 42 males).

## 4. Discussion

### 4.1. Urinary concentrations of phthalate metabolites and phenols

Compared to US adults from the general population during the same period (Centers for Disease Control and Prevention, 2014), we observed concentrations about 9 times higher for benzophenone-3 while concentrations were similar for the other phenols and phthalate metabolites in our study population (Appendix, Table A5). The fact that our study took place in California and enrolled highly educated (72% had at least a bachelor or associate degree), mothers (90% of the study population were female) with a young children, along with the low percentage of African American subjects (only 2% compared to more than 10% in the US general population in 2009 (United States Census Bureau, 2012) might explain the relatively high benzophenone-3 concentrations observed. Being White, female, highly educated as well as having a young child have been associated with higher benzophenone-3 concentrations and higher use of sunscreen in previous studies (Calafat et al., 2008; Santmyire et al., 2001; Wolff et al., 2010; Wu et al., 2010). Season of sampling (higher concentrations during summer compared to winter) (Calafat et al., 2008; Wolff et al., 2010) is also a predictor of benzophenone-3 concentrations. However in both NHANES and our study, urine collection tended to be balanced over the year (Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS), 2015).

We observed positive correlations between biomarker concentrations measured in adults and their children suggesting common sources of exposures to these chemicals between these household members. The strongest correlation coefficient was observed for benzophenone-3, followed by triclosan and butyl paraben. We observed higher urinary concentrations of benzophenone-3, methyl, propyl and butyl paraben in adults compared to their children, while MBP and MiBP concentrations but not MEP concentrations were higher in children compared to their parents. Similar findings have been observed in studies performed previously among children of the same age range (Frederiksen et al., 2013; Kasper-Sonnenberg et al., 2012; Larsson et al., 2014).

In SUPERB, repeated urine samples were collected on average one year apart. Only a few studies have reported long term (e.g., over years) variability in urinary concentrations of phthalates (Townsend et al., 2013) and phenols (Engel et al., 2014) in adults. Comparisons of results across these studies must acknowledge differences in the study populations (Californian males (10%) and females (90%), SUPERB – our study, female registered nurses from 11 U.S. states (Townsend et al., 2013) or women from Shanghai (Engel et al., 2014)), timing of urine collection (end of the day (95% in SUPERB), first morning void (Townsend et al., 2013) or random spot urine sample (Engel et al., 2014)) and the time elapsed between the urine collections (1 year (SUPERB), 1–3 years (Townsend et al., 2013) or 6.7 years (Engel et al., 2014)). Compared to intra-individual correlation coefficients for MEP, MiBP and MBP (0.53, 0.47 and 0.44, respectively) among the registered nurses (Townsend et al., 2013), we observed somewhat lower correlations (0.44, 0.39 and 0.25) in SUPERB adults. Regarding phenols, correlation coefficients were higher in our population for methyl and propyl paraben (0.53 and 0.64, respectively) compared to the study published by Engel et al. (0.44 and 0.41, respectively). To our knowledge, no study had previously reported long term variability in urinary concentrations for benzophenone-3 and triclosan in adults.

Overall we observed higher variability (i.e., lower Spearman correlation coefficients) in children compared to their parents. This finding might be explained by changes in both behaviors related to phenol and phthalate exposures (e.g., diet, type of PCPs used) and physiology/metabolism; these changes are likely to be greater in children compared to adults. Data regarding phenol and phthalate urinary concentration variability among children were sparse (Teitelbaum et al., 2008; Watkins et al., 2014). Correlation coefficients for benzophenone-3 and triclosan concentrations in urine samples collected 12 weeks apart among 6–10 years old children ($\rho=0.45$ and 0.52 for benzophenone-3 and triclosan, respectively, (Teitelbaum et al., 2008)) were similar to those observed in our study in which urine samples were collected about one year apart ($\rho=0.42$ and 0.47). Regarding phthalates, compared to another study collecting urine samples one year apart at ages 1–5, correlation coefficients observed in our study were similar for MEP and MiBP and slightly higher for MBP ($\rho=$ 0.32, 0.39 and 0.36 for MEP, MBP and MiBP, respectively in our study compared to 0.35, 0.20 and 0.31 (Watkins et al., 2014)).

Except for triclosan (kappa=0.5 in adults), in both adults and children, we observed weak Cohen's kappa coefficients, suggesting weak agreement between the concentrations (coded in tertiles) measured in the repeated samples.

### 4.2. Exposure to phenols and phthalates through use of PCPs

In line with previous studies (Berman et al., 2009; Braun et al., 2013b; Parlett et al., 2013; Romero-Franco et al., 2011), we observed higher MEP, methyl, propyl and butyl paraben concentrations with increasing number of PCPs used in the past 24 h in adults, suggesting that, although non-specific, questionnaires might be useful tools to estimate exposure to these chemicals in adults. We did not observe any association between the number of PCPs used and biomarker concentrations among children, maybe because they used on average fewer PCPs than their parents.

DEP is used as a solubilizer, denaturant and to make the scent linger in fragranced products. Use of colognes and perfumes has been previously associated with increased MEP concentrations in adults (Braun et al., 2013b; Duty et al., 2005; Just et al., 2010) and 8–13 year old children (Lewis et al., 2013). In SUPERB participants, we observed suggestive evidence associating use of colognes or perfumes with MEP concentrations in adults ($p$-Value=0.06). Few children used perfumes precluding study of this association ($n=3$ and 1 at first and second study visits, respectively). Other PCPs associated with increased MEP concentrations in previous studies included lotions, colored cosmetics (hair dye, foundation, blush, eye shadow, eye liner, or mascara), aftershaves and nail polish in adults (Braun et al., 2013b; Duty et al., 2005; Just et al., 2010) and hair care products and deodorants (girls only) in children (Watkins

et al., 2014; Lewis et al., 2013). In our study population, only the use of lip balm in adults and liquid soap in children were significantly associated with MEP.

Discrepancies in the findings across studies exploring the associations between PCP use and biomarker concentrations might be due to differences in questionnaire design (e.g., 24 versus 48 h recalls), timing of urine sample collection (e.g., collection of end of the day urine sample, compared to first morning void), variability in types and brands of PCPs used across populations and year of the studies. A recent study using NHANES data reported temporal trends in urine phthalate concentrations. Concentrations of MBP and MEP declined from 2001 to 2010, while MiBP concentrations increased (Zota et al., 2014). These trends likely reflect modifications in industrial practices and phthalate contents of PCPs sold in 2007–2009, when our study took place, might be different from those sold now. The age of the study participants may also explain discrepancies in the findings across studies, especially for children.

The total number of PCPs used was not clearly associated with benzophenone-3, triclosan, MBP and MiBP concentrations in adults and children. However, in adults, we observed increase biomarker urinary concentrations of these biomarkers with the use of specific PCPs, such as shaving cream (benzophenone-3), sunscreen (benzophenone-3) and Colgate® toothpaste (triclosan). The positive association between benzophenone-3 and sunscreen has been previously observed (Meeker et al., 2013) and was expected since this chemical is an UV-filter commonly used in sunscreen (Dodson et al., 2012). In the US, the Colgate Total® toothpaste is the only FDA-approved toothpaste containing triclosan and our results showing higher triclosan concentration among users of this brand are in line with those of an interventional study in which urinary concentrations of this antibacterial declined after replacement of participants' usual toothpaste containing triclosan by one without this compound (Koch et al., 2014).

To the best of our knowledge, this is the first study to report associations between PCP use in the past 24 h and exposure to triclosan, parabens and benzophenone-3 among children. Among them, use of sunscreen in the past 24 h was associated with higher concentrations of benzophenone-3, methyl paraben and MBP; while users of hair care products had on average higher urinary concentrations of butyl paraben. As we observed in adults, children using Colgate® toothpaste had higher triclosan levels than those using another brand.

### 4.3. Limitations

This study had several limitations. We did not collect information on the amount of PCPs used, and, except for toothpaste for which we used brands (Colgate versus other), we classified PCPs by category of products. Also, we did not measure the phthalate and phenol content of the specific PCPs used. Because two similar products from different brands likely contain different amount of the chemical of interest, exposure misclassification may have been present in our analysis (Duty et al., 2005).

Phenols and phthalates have short half-lives in humans. A rise in urinary concentrations of some phenols and phthalates has been observed in samples collected near the time of a known exposure (use of a specific or association of specific PCPs (Koch et al., 2013, 2014)). We collected only one urine sample at the end of the day and may have missed the rise in urinary concentrations following PCP use (Koch et al., 2013; 2014), especially if PCPs were used in the morning. For this reason, our study might have underestimated the associations between PCP use and phenol and phthalate metabolite urinary concentrations. The relatively small sample size may also have limited our ability to detect associations. Finally, our population is not representative of the US general population, with regard to education level and race/ethnicity.

## 5. Conclusion

Benzophenone-3 and paraben concentrations were higher in adults compared to their children, while children had higher MBP and MiBP concentrations. Overall, Spearman correlation coefficients between repeated measurements in children were lower than those observed in adults. Our results, with those of previous studies (Braun et al., 2013b; Duty et al., 2005; Watkins et al., 2014) suggest that use of PCPs represents a non-negligible part of the total exposure to certain phenols, parabens and some phthalates (especially DEP) in both adults and children. When biologic specimens are not feasible, use of questionnaires may be useful as a broad indicator of exposures to parabens and DEP in adults.

## Study approval

The SUPERB study protocol has been approved by the Institutional Review Board at the University of California, Davis (UC Davis). Informed consent for participation was obtained before data or specimen collection. The involvement of the Centers for Disease Control and Prevention (CDC) did not constitute engagement in human subject research.

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## Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

## Conflict of interest

None.

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## Appendix A. Suplementary Information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.04.009.

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