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Integrating habits and practices data for soaps, cosmetics and air care products into an existing aggregate exposure model

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ABSTRACT

In order to accurately assess aggregate exposure to a fragrance material in consumers, data are needed on consumer habits and practices, as well as the concentration of the fragrance material in those products. The present study describes the development of Phase 2 Creme RIFM model by expanding the previously developed Phase 1 model to include an additional six product types. Using subject-matching algorithms, the subjects in the Phase 1 Creme RIFM database were paired with subjects in the SUPERB and BodyCare surveys based on age and gender. Consumption of the additional products was simulated to create a seven day diary allowing full data integration in a consistent format.

The inhalation route was also included for air care and other products where a fraction of product used is inhaled, derived from the RIFM 2-box model. The expansion of the Phase 1 Creme RIFM model has resulted in a more extensive and refined model, which covers a broader range of product categories and now, includes all relevant routes of exposure. An evaluation of the performance of the model has been carried out in an accompanying publication to this one.

1. Introduction

The Research Institute for Fragrance Materials, Inc. (RIFM) has been engaged in the generation and evaluation of safety data for fragrance materials since its inception 50 years ago. The safety evaluation of fragrance ingredients presents unique challenges principally due to the fact that there are over 2100 chemically defined fragrance ingredients in commerce, the vast majority of which are used at low levels.

Over time, RIFM's approach to gathering data, estimating exposure and assessing safety has evolved as the tools for risk assessment evolved. The publication by Api et al. (2015) provides an update of the RIFM safety assessment process, which follows a series of decision trees, reflecting advances in approaches in risk assessment and new and classical toxicological methodologies employed by RIFM over the past ten years. One of the key changes included in this update was incorporating an aggregate exposure assessment methodology.

Consumer exposure to fragrance materials can occur through multiple routes; dermal, inhalation and oral. As such, exposure estimation to fragrance ingredients in cosmetics, personal care products and air care products to members of a population is necessary to enable safety assessments. Systemic exposure estimates to fragrance ingredients are typically below thresholds of toxicological concern (TTC) (Safford et al., 2017). Screening or first-tier methods used to calculate aggregate consumer exposure rely on the summation of high percentile product consumptions, amounts per use and concentrations of chemical/fragrance in products to calculate a worst case exposure scenario (SCCS, 2012).

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While such methods are useful and easy to implement, refined techniques are required should the initial exposure estimate prove too high. Additionally, higher tier methods for estimating exposure are a useful tool when developing alternative approaches to risk assessment to reduce animal testing. The safety assessment described by Api et al. (2015) begins with a thorough analysis of existing data followed by in silico analysis, identification of 'read across' analogues, generation of additional data through in vitro testing. In order for these tools to be relevant for assessing safety in humans, the exposure calculations should reflect realistic aggregate exposure to fragrance materials from all sources.

High-tier and more refined aggregate exposure estimation rely on large data sets of the aforementioned parameters to calculate a distribution of exposure so that population percentile statistics can be calculated, with the higher percentiles used for risk assessment. This approach is comparable with previous models already published in the literature. In previous studies, habits and practices data on cosmetic and personal care product use were probabilistically combined with amount per use data to estimate exposure in the European population (McNamara et al., 2007). A similar methodology was employed for aggregate exposure to other products for EU (Hall et al., 2007, 2011) and US populations (Loretz et al., 2005, 2006, 2008). Biesterbos et al. (2013) captured survey data on the habits and practices of the use of cosmetics and personal care products from 516 subjects from the Netherlands through web-based questionnaires. In this study, the amount per use data was collected based on photographs of the likely amount that the respondent typically uses to infer a numerical value (gram or ml). Based on this data, the Probabilistic Aggregate Consumer Exposure Model (PACEM) was developed which uses Monte Carlo techniques with repeated random sampling methods to simulate a larger sample size to estimate population aggregate exposure percentile statistics for chemicals decamethylcyclopentasiloxane (Dudzina et al., 2015) and geraniol (Nijkamp et al., 2015).

Another example of a high tier aggregate exposure model is the Creme RIFM Phase 1 model (Comiskey, 2015), which utilized a large scale market research survey to determine consumer habits and practices for 19 cosmetics and personal care products based on 36,446 individuals in the United States ('US') and Europe ('EU'). The model consisted of separate data sets: frequency of product use, amount per use, fragrance ingredient concentration in mixture, fragrance mixture concentration in product and body measurements. These data were probabilistically combined using Monte Carlo simulations based on subject demographics. Distributions of fragrance ingredient and fragrance mixture concentration data were obtained from industry and were analysed by the aforementioned model to calculate aggregate exposure to the individual fragrance ingredients via dermal and oral routes (Safford et al., 2015). However, this model did not cover some important product categories (namely soaps, hairspray, and air care products), nor was inhalation included as a route of exposure which can be an important route for fragrances.

Inhalation models have been developed as stand-alone models with varying degrees of complexity (Park et al., 2006), and have recently been included as part of an aggregate exposure model containing habits and practices data (Dudzina et al., 2015). In the present study, the inclusion of inhalation exposure via the respiratory tract to the Phase 1 model completes the three relevant routes of exposure (including dermal and oral) necessary for estimating total systemic exposure (SCCS, 2012). Also, the database is expanded to include six other common personal care products (bar soap and liquid hand soap), cosmetics (hair spray) and air care products (scented candles, plug-in fresheners and aerosol air fresheners). The additional products were chosen as they commonly contain fragrance ingredients and they are used regularly by both males and females. These model updates form the basis of what will be called the Phase 2 Creme RIFM model, and represents a novel use of both the RIFM 2-box inhalation exposure model and the integrated survey data.

Due to the lack of data for air care product usage for the subjects already in the database, it was necessary to combine different consumption surveys, each containing information on the habits and practices of different types of products. However, the consumption data for some of the newer products (namely air care) were collected and recorded using different methodologies and so are in different formats to the data in the previous Phase 1 study. Therefore, the newly acquired data were integrated by way of simulation techniques, by pairing subjects with similar demographics in the different surveys – a technique which we refer to as "demographic pairing". The approach assumes that subjects in similar demographics (age range, gender, and geography) will have similar habits and practices for different sources of exposure (e.g. cosmetics and air care use). Using demographic pairing in combination with random simulation allows a large number of possible habits and practices across different product types to be developed, which is still grounded in real data and avoids the need to make conservative assumptions when aggregating across different survey types. A summary of the model and the areas in which it has been extended can be seen in Fig. 1. A more detailed and mathematical description of the model can be found in Comiskey and AA (2015).

The updated Creme RIFM model contains a broader number of sources and routes for evaluating consumer aggregate exposure to fragrance materials. In general, mathematical exposure models require detailed evaluation in order to verify their correct implementation, realism, applicability, and consequences with regards to human health. This was carried out in a parallel study and published in (Safford et al., 2017), where eight fragrance materials were analysed using concentration data supplied by industry. The focus of this publication on is on the development of the model and the underlying data used to support it.

2. Methods

To account for exposure to the additional products in the Phase 2 model, four additional data sets were integrated: 1) frequency of product use based on habits and practices surveys, 2) amounts of product used per occasion, 3) dermal retention factors and 4) the portion of emitted product inhaled or the inhalation exposure fraction. The inhalation exposure fractions were calculated based on an existing compartmental inhalation model (RIFM 2-Box model; Singal et al., 2010; Petry et al., 2014), while the product amount per use data and the specific dermal retention factors for the additional products could be found in the literature (Hall et al., 2007; 2011, Loretz et al., 2005, 2006; 2008).

2.1. Habits and practices surveys

Integration of the new products required additional surveys with similar sets of subjects who share demographic attributes as in the Phase 1 habits and practices database; it was assumed that their consumption patterns are likely to be similar to one another, which was congruent with the assumption that amounts data from one survey can be paired with habits and practices data from another survey based on demographic pairing (Comiskey and AA, 2015; McNamara et al., 2007; Hall et al., 2007, 2011). Full details of how this was carried out can be found in Section 2.5.

There were three habits and practices surveys acquired for the calculation of frequency of use for the additional cosmetic, personal care and air care products: 1) Kantar Worldpanel survey for hair

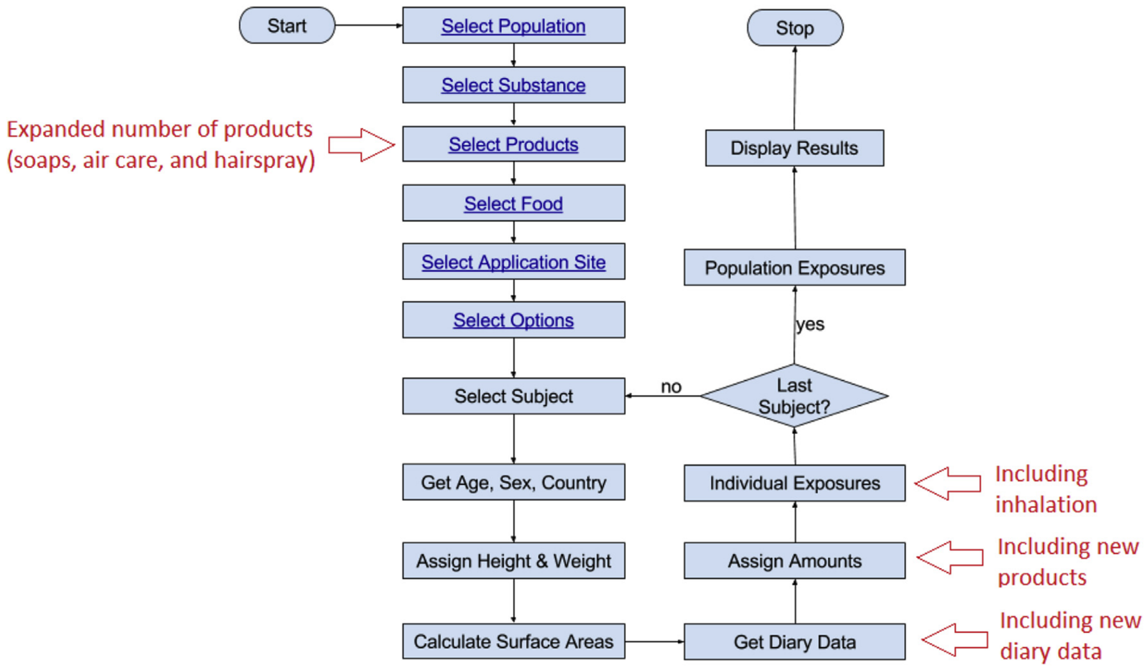

Fig. 1. Flow chart of model with extensions highlighted in red.

spray and bar soap (bath and shower) usage, 2) 'SUPERB' survey for scented candles, aerosol air freshener and plug-in air freshener usage, and 3) 'BodyCare' survey for bar soap (hand washing) and liquid hand soap usage. In the aforementioned surveys, all study participants used their own products available in their homes or office, thus covering a wide range of brands. Therefore the participants only recorded the use of products that they are accustomed to using.

2.1.1. SUPERB survey

The 'Study of Use of Products and Exposure-Related Behavior' (SUPERB), funded by the US EPA, investigated use patterns of cleaning products and air fresheners along with the frequency of performing different cleaning tasks among 612 California residents between 2006 and 2009 (Moran et al., 2012a,b). The subject age groups were defined as either 'Parents with Young Children' or 'Older Adults'. Older adults were defined as residents who are "generally aged 55 or above", however, there was no specified age range provided for "parents with young children". Therefore, it was assumed that the parents with young children are between 18 and 54 years of age.

The SUPERB study acquired monthly frequency of product use for air care products, including scented candles, and aerosol air fresheners, where the subjects undertook phone and web-based surveys. For plug-in air fresheners, frequency of use was not obtained and therefore subjects were either considered users or non-users, based on whether they reported using the plug-in air fresheners or not. In all cases, frequency data was obtained by surveying how many times products were used over a given period of time, i.e. number of uses per day, month, week or year.

The SUPERB study contained relevant data which could be used to simulate daily frequency of use. Although the data were acquired for subjects in the US, specifically California, it was assumed that similar air care usage patterns exist in the EU. This was a reasonable assumption given the similarity in the percentage of air care product consumers between EU and US studies (Table 1). It should be noted that the closest similarities in the percentage of total air care users were found in cases where there was little ambiguity regarding the product type based on its description.

2.1.2. Kantar survey

Kantar Worldpanel conducted a survey of cosmetics and toiletries habits and practices for market research purposes between 2007 and 2008. The survey consisted of a collection of individual daily diaries of product consumption by 36,446 of male and female subjects across EU counties and the US. Importantly, this Kantar survey was used in the Phase 1 Creme RIFM model.

The frequency of hair spray and bar soap (bathing/showering) use was collected during the Kantar Worldpanel survey which the Phase 1 Creme RIFM model and databases were originally built upon (Comiskey and AA, 2015). Conveniently, this meant that the same subjects in the Phase 1 Creme RIFM database also used hair spray and bar soap (bathing/showering), thus making expansion of the product range relatively simple.

This Kantar survey did not have any robust data on hand soap usage, and so data on hand soap usage was obtained from the BodyCare survey.

2.1.3. BodyCare survey

The Procter and Gamble Company conducted an internal study in 2010 known as 'H + P Body Care', hereafter referred to as 'BodyCare', which consisted of 448 US subjects aged 18–64 who logged their hand washing habits for liquid hand soap and bar soap, among others (Tozer et al., 2015). This data set contained frequency of hand washing per day and product co-use patterns for each subject. The 448 subjects were divided into different age groups (Table 2).

The subjects filled out an on-line questionnaire where they were asked to indicate typical daily use of hand washing products. In the BodyCare survey, there were 6 distinct products including liquid hand soap and bar soap that subjects used to wash their hands. The subjects selected the hand washing frequency that best described them and would select a quantitative description, such as "1 time per day", "11–20 times per day" or "50+ times per day".

Table 1
Air care product consumer use comparison between separate studies in EU and US.

(EPHECT study; Johnson and Lucica, 2012)		(SUPERB study; Moran et al., 2012a,b)	
EU Product Description	% Users	US Product Description	% Users
Air fresheners in sprays	48%	Air Freshening Sprays	48%
Electric air fresheners	22%	Plug-ins	22%
Passive air fresheners (units/devices containing a gel, liquid or wipes/tissues)	20%	Oils or Air Freshening	15%

Table 2
Number of subjects in BodyCare survey by age and gender.

Age groups	Male	Female
18–24	20	20
25–34	30	55
35–44	73	61
45–54	54	44
55–64	48	42

The subjects were also asked to select a qualitative description of their co-use habits that best describes the usual product used to wash the hands (in last 6 months). For example, options were given to determine the breakdown of hand washing product co-use, such as "[I use] bar soap and liquid hand soap, but mostly bar soap, "bar soap and liquid hand soap equally" or "liquid hand soap only".

Due to the high frequency of hand washing occasions that individuals undergo each day, it was necessary to use the BodyCare survey which specifically focused on collecting subjects' hand washing habits and practices to expand the Creme RIFM database. Furthermore, the co-use of bar soap and liquid hand soap along with the frequency of hand washing provided a useful description of hand washing habits and practices, which could be simulated in the Creme RIFM model.

2.2. *Amount per product use*

The hair spray (aerosol) amount per use was based on a lognormal distribution fit to summary statistics for 360 female subjects in the US aged 19–65 (Loretz et al., 2006). It was assumed that the distribution of hair spray amount per use for US females were applicable for male users in the EU and US, and female users in the EU.

For scented candles, the single point value of 9.6 g according to the RIFM 2-box indoor air dispersion model was utilised which was calculated based on a burn rate of 67 mg/min (industry data, 2-box model) and a burn duration per day of 144 min (Torfs et al., 2008). The distributions of amount per use data for plugin and aerosol air fresheners were calculated based on a combination of triangular distributions of emission rates (g/sec) and individual emission durations (sec) from the literature (Table 3).

The liquid hand soap amount per use data was based on a study conducted by the Danish EPA on the average amount per use from five different liquid hand soap dispensers on males and females aged 28–61 in the workplace, where hand washing from "dirty labour" was not required (Larsen and Andersen, 2006). Each of the five dispensers contained fragranced liquid soap with different viscosities, pumping devices, and therefore, different flow rates. The participants recorded the number of dosages for each hand washing event which was used to estimate the average amount per use. Data was collected on two occasions for four of the five dispensers allowing the estimation of nine average amounts per use values, where it was found that the overall average from all five dispensers was 0.92 g. The full list of mean amount per use values, which represents the possible values that can be used in the exposure model are presented in Table 4.

In the present study, the amount per use data for bar soap (hand washing) was inferred using a scaling factor to adjust the above liquid hand soap amount per use data. According to the EU Technical Guidance Document an average of 0.8 g for solid bar soap was used for each hand washing event (EU TGD, 2003). Therefore based on average bar soap and liquid hand soap amount per use, a scaling factor was derived (0.8 g/0.92 g = 0.87) to adjust the average liquid hand soap amount per use to represent bar soap usage as a distribution of data, thus giving the data in Table 4.

The amount per use of bar soap used during showering was measured for ten Dutch adults by The National Institute for Public Health and the Environment (RIVM) in an internal study (Bremmer et al., 2006) and described elsewhere (Bremmer et al., 2006). It was found that the ten subjects used an average of 4.73 g of soap per shower ranging from 1.13 to 12.9 g (listed in Table 4).

It was assumed in the present study that the amount per use

Table 4
Mean amount per product use for liquid hand soap, bar soap (hand washing) and bar soap (showering).

Liquid Hand Soap	Bar Soap (hand washing)	Bar Soap (showering)
Mean amount per use value in grams		
0.58	0.50	1.13
0.74	0.64	1.36
0.86	0.75	1.87
0.88	0.77	3.93
0.96	0.83	4.14
1.00	0.87	4.80
1.04	0.90	5.03
1.15	1.00	5.56
1.27	1.10	6.6
–	–	12.9

Table 3
Calculated amount per use triangular distributions for aerosol and plugin air fresheners.

Product type	Emission rate (g/sec)[a]			Emission duration (sec)	Calculated amount per use[d] (g)		
	Min.	Max.	Typ.		Min.	Max.	Typ.
Aerosol air freshener	0.6	1.5	0.9	5[b]	3	7.5	4.5
Plugin fresheners	6.9×10^{-6}	1.4×10^{-5}	1.2×10^{-5}	86,400[c]	0.6	1.2	1.04

[a] AISE (2015).
[b] Based of emission duration for aerosol air freshener spray, Torfs et al. (2008).
[c] Based on continuous emission (24 h/86,400 s).
[d] Emission rate × emission duration.

data for showering could be used for other soap use such as bathing or other body washing practices. It should be noted that according to a study by EPA exposure factors handbook, bath soaps were used on average 2.6 g per product application based on a survey of 20 companies (EPA, 2011), which falls within the range of the above distribution of bar soap amount per use.

2.3. Inhalation modelling

Many inhalation models are time dependent systems, and thus cannot be readily integrated into a probabilistic model. Instead, here we utilized the proportion of emitted product that is inhaled, referred to as an inhalation fraction, which can then be applied to the amount of product applied as discussed previously. To calculate the ratio of total amount of product released into the air and the amount inhaled by a subject, the time dependent RIFM 2-box inhalation model was utilized, which can be used to estimate the amount of physical product emitted that could be inhaled. The model can be used for both far-field and near-field analysis of exposure from aerosol air fresheners, scented candles, and plugin air fresheners, using a "room within a room" type of configuration with air flows between rooms/boxes described using a system of ordinary differential equations (Nicas, 2009). The primary inputs for the model are room/box volumes, air flow rates, product spray/emission rates, inhalation rate, and residence time of the consumer in the various zones. The model can therefore be used to estimate the total amount of product inhaled in a given application event, which is labelled the inhalation fraction. The default assumption in the model is that 100% of material emitted from the product is volatile, which is a conservative assumption. This ratio provides an inhalation exposure fraction used in aggregate exposure modelling (Dudzina et al., 2015), which is akin to a retention factor for dermal exposure. The inhalation model was based on two mass balance equations that described the flow of a fragrance through two locations in a room or a house which were solved by way of the forward Euler method in the original implementation (Singal et al., 2010). The time dependency occurred through the four main parameters that the model was based on: fragrance emission rate, room and house air flow parameters, inhalation rate and time spent in different locations within a room or house. Importantly, single default values were used in the aforementioned parameters, as specified in the 2-box model. Therefore, total exposure from a usage event could be utilized to derive single inhalation exposure fractions for the different products. Note, the use of high single-valued default parameters, as opposed to a distribution, provides conservative default values (Singal et al., 2010). For example, the following assumptions were made: 100% of material emitted from product was volatile, complete homogeneous dispersion through rooms/house, the sizes of the rooms/house were on average smaller than the typical EU home and finally, the human ventilation rate was based on a non-sedentary solitary individual with moderate level of activity.

In total, there were seven products that are likely to be inhaled in the Phase 2 Creme RIFM model: deodorant spray, eau de toilette, eau de parfum, hair spray, scented candles, plug-in fresheners, and aerosol air fresheners. The former three personal care products were developed previously in the Phase 1 Creme RIFM model, but this only included estimations of exposure from the dermal route. It should be noted that body spray (featured in the Phase 1 model), despite being an aerosol product, was assumed to have a dermal retention factor of 100% and was therefore exempt from inhalation exposure modelling. This assumption can be refined at a later date if found to be restrictive.

The inhalation factors were calculated specifically for each of the aforementioned products. It should be noted that the inhalation exposure fraction will depend on the product, how it is used and where it is used within a room of a house. Air care products are not directed at the skin and therefore, in general, the only significant exposure route is through inhalation. Some personal care spray products are directed near to the face and may be inhaled. The 2-box model also makes conservative assumptions about how the fragrance circulates within a room for personal care products, or throughout rooms in a house for air care products and how much time a user spends in a location within the room/house. The 2-box model assumptions and parameters can be accessed through the software package itself (TwoBox1.17, RIFM Inc., NJ, USA).

To calculate the inhalation factors the cumulative systemic exposures from the inhalation route where used, which provide a quantitative measurement of the total exposure to a fragrance over time of application (μg/day). The cumulative inhalation exposure was calculated by adding up (integrating) the concentration of a fragrance in air over time multiplied by the inhalation rate of a person for a time they could be present in each room. The inhalation fraction was calculated from the ratio of the amount of fragrance material released into the air and the amount that was inhaled by the subject (cumulative inhalation exposure). In the example of plugin air fresheners, a total of 55.728 mg was released into the house, whereas the cumulative inhalation exposure was 0.265 mg which means 0.48% of the product was inhaled. This represents the inhalation exposure fraction (0.0048) for this product (Table 5).

2.4. Retention, inhalation and penetration factors

The dermal retention factor is an estimate of how much of the product will remain on the skin after rinsing/washing, and values were taken from (Api et al., 2008), with the exception of deodorant spray, eau de toilette and eau de parfum (Table 5). The dermal retention factor for deodorant spray was based on Steiling et al. (2012), where it was shown that of the amount of spray that was directed to the underarms, only 23.5% actually landed on the skin. This is a conservative assumption as much of the spray product will not reach the user's skin. The remainder of the deodorant spray that does not land on the skin (76.5%) is released into the air and, therefore, could be available for inhalation. According to the 2-box model the percent of fragrance inhaled from deodorant spray, assuming all of it was released into the air is 0.58%. However, only 76.5% is actually available for inhalation. Therefore, it was necessary to calculate an adjusted inhalation exposure fraction, which is a multiplication of the 'Fraction of Fragrance Available for Inhalation' and the 'Fraction of Fragrance Inhaled' for a specific product. This produced an adjusted inhalation exposure fraction of 0.0044 for deodorant spray ($0.765 \times 0.0058 = 0.0044$ or 0.44%). The inhalation exposure fractions were calculated for all relevant products (Table 5).

Lastly, the dermal penetration factor depends on a number of factors including body part, skin type, product type, and chemical type. Initially in this study, a conservative dermal penetration factor of 100% will be used for products applied to the skin. It was also assumed in the 2-box model that all of the fragrance that was inhaled was absorbed through the respiratory tract (Singal et al., 2010), thus giving us a respiratory absorption factor of also 100%. It should be noted that these conservative assumptions around dermal absorption and respiratory tract absorption could be refined if specific data are available on the fragrance material of interest.

Table 5
Dermal retention factors and inhalation exposure fractions.

Product	Exposure Route	Dermal Retention Factor	Fraction of Fragrance Available for Inhalation	Fraction of Fragrance Inhaled[1]	Inhalation Exposure Fraction
Deodorant spray	Dermal/ Inhalation	0.235[a]	0.765	0.0058	0.0044
Hair spray	Dermal/ Inhalation	0.1[b]	0.9	0.0056	0.005
Eau de toilette	Dermal/ Inhalation	0.8[c]	0.2	0.0063	0.0013
Eau de parfum	Dermal/ Inhalation	0.8[c]	0.2	0.0063	0.0013
Aerosol air freshener	Inhalation	–	1	0.0014	0.0014
Plugin air freshener	Inhalation	–	1	0.0048	0.0048
Scented candles	Inhalation	–	1	0.0079	0.0079
Bar soap	Dermal	0.01[b]	–	–	–
Liquid hand soap	Dermal	0.01[b]	–	–	–

[1]Calculated from 2-box model.
[a] Steiling et al. (2012).
[b] Api et al. (2008).
[c] Internal study conducted by The Procter and Gamble Company on pump sprays.

2.5. Merging subjects between different studies

The Phase 1 habits and practices database had many more subjects (N = 36,446) in comparison to the SUPERB survey (N = 437) and the BodyCare survey (N = 448), and contained more detail in terms of consumption (product use documented by the hour for 7 consecutive days compared to monthly and daily approximate frequency of use, respectively). Hence, the Phase 1 habits and practices database was used to act as a base through which the other additional surveys merge with. The approach simulated the consumption data from SUPERB and BodyCare into the detailed diary-style data structure to correspond with the Kantar data.

While the SUPERB and BodyCare surveys are considerably smaller in size than the Kantar survey, their sample sizes are adequate for estimating high percentiles (EFSA, 2011). The European Food Safety Authority guidance details a technique for estimating adequate sample sizes when conducting population-based exposure studies, yielding minimum sample sizes for the 95th and 99th percentiles of 59 and 298 respectively. However, as with all surveys, care should be taken when stratifying the population into smaller subpopulation which may lead to inadequate sample sizes for estimating higher percentiles.

To merge the consumption data, commonalities between subjects from the three surveys were determined. The most basic information on all subjects was their gender and age group. However, there was a discrepancy between the demographic age grouping between Kantar, BodyCare and SUPERB subjects. Therefore, it was necessary to assume that certain age groups were equivalent and might share similar consumption characteristics (Table 6).

2.5.1. Simulating hand soap consumption

In the present study, the scenarios which best describe subject co-use between bar soap and liquid hand soap were converted to ratios of two probabilities (Table 7). For example if a subject recorded that they use “Both bar soap and liquid hand soap, but mainly bar soap”, a ratio of 66:33 was assumed in favour of bar soap. Alternatively, if a subject used both products equally a ratio of 50:50 was assumed.

Table 6
Merging of BodyCare and SUPERB subjects with Kantar subjects by age group.

Kantar Age Groups		BodyCare Age Groups		SUPERB Age Groups
18–24	→	18–24	→	18–54
25–34	→	25–34	→	18–54
35–49	→	35–44	→	18–54
50–64	→	45–54	→	55+
65+	→	55–64	→	55+

Based on the daily frequency of hand washing and the probability of which product was used (Table 7) it was possible to estimate the frequency of liquid hand soap and bar soap consumption per day for each subject. This was achieved by multiplying the frequency of hand washing per day by the probability of liquid hand soap and/or bar soap use. For example if a subject washed their hands eight times per day and used “both bar soap and liquid hand soap, but mainly bar soap”, then their usage could be described mathematically, thus

Bar soap frequency of use per day: $8 \times 0.66 = 5.28 \approx 5$
Liquid hand soap frequency of use per day: $8 \times 0.33 = 2.64 \approx 3$

However, if their usage was described as being between “11–20 times per day”, this was treated mathematically as a uniform distribution, where there was an equal chance of the individual using any number between 11 and 20 times per day. To select a number from this uniform distribution, random selection was used by way of Monte Carlo simulation.

2.5.2. Simulating air care consumption

The SUPERB data did not include habits and practices data recorded on a daily basis, as was the case in the Kantar survey. This meant that although the frequency of monthly use was known, the days of the week a user consumed the products were not known. Hence, it was necessary to probabilistically build a daily usage diary that was representative of each subject in the SUPERB data. This was achieved by taking the number of monthly product uses for each subject, and randomly choosing days of the month that each subject consumed the product and placing one usage event in that day of the month until all monthly uses were randomly allocated. From the simulated daily uses throughout a month, 7 random days of product use were chosen and placed sequentially next to one another to form one whole week of product usage. This meant that some days, depending on number of product uses, can have no product use events, whereas, other days may have several product uses as would be expected in reality. Lastly, it was assumed that if a

Table 7
Co-use choices and probability of using the different products based on the recorded responses.

Co-use Description	(Probability of Use, %)	
	Bar soap (hand washing)	Liquid hand soap
Bar soap only	100	0
Liquid hand soap only	0	100
Both bar soap and liquid hand soap, but mainly bar soap	66	33
Both bar soap and liquid hand soap, but mainly liquid hand soap	33	66
Equally bar soap and liquid hand soap	50	50
(Other)	0	0

subject uses plugin fresheners they were constantly present in the home and so they were exposed to them every day of the week.

2.5.3. Simulating the phase 2 database

Integrating the simulated SUPERB and BodyCare daily consumption with the Phase 1 habits and practices database required some assumptions and the application of mathematical modelling techniques. Firstly, it was assumed that US subjects in the BodyCare and SUPERB surveys had similar habits and practices to EU subjects. Secondly, it was assumed that individuals wash their hands the same number of times every day using the same soap products i.e. liquid hand soap and/or bar soap (hand washing). Lastly, it was assumed that different subjects had similar habits and practices based on their age and gender. With regards to integrating and simulating the soap and air care daily consumption with the Kantar survey data, the following algorithm was used

1. For each subject in the Phase 1 habits and practices database, determine their gender and age group.
2. Randomly select a 'similar' subject from the BodyCare Diary and SUPERB survey who were of the same gender and within the same approximate age group as the subject in the Phase 1 habits and practices database (defined in Table 6).
3. For the similar subject in the BodyCare survey, determine the soap products used and the frequency of use per day. Repeat this daily consumption to 7 days of the week to coincide with Phase 1 habits and practices database.
4. For the similar subject in the SUPERB survey simulate their air care product usage over the seven day period.
5. Integrate the soap and air care usage with the other personal care product usage within the Phase 1 habits and practices database to produce the Phase 2 database.

It should be noted that when a subject in the consumption survey used bar soap for hand washing i.e. where soap was applied to palms and back of the hands, then the bar soap (hand washing) amount per use data was sampled from. Conversely, when bar soap was applied to any other parts of the body, then the bar soap (showering/bathing) amounts per use data was sampled from.

3. Results

3.1. Analysis of SUPERB and BodyCare survey data

The original SUPERB data allows product use, co-use and non-use data to be analysed within the sample population (Table 8). It was found that 24.7% of all subjects do not use an air care product at all. Amongst air care product users, people are most commonly exposed to scented candles in the home. Generally speaking, there was little difference between males and females. Interestingly 8.2% of the sample population used all three air care products.

It was found that a significant proportion (21%) of BodyCare participants wash their hands 5 times a day, with an almost equal proportion (19%) washing their hands 10 times a day (Table 9).

It was found that liquid hand soap was the predominant product used for washing hands (51.8%; Table 10). Over half of the subjects use only liquid hand soap to wash hands, and a further 17.2% use liquid hand soap most of the time, and bar soap some of the time. It was found that of the 448 subjects from the BodyCare survey, only 6.5% used neither liquid hand soap nor bar soap (hand). These 29 individuals are considered non-consumers of soap and thus

Table 9
Typical frequency of washing hands according to BodyCare survey.

Frequency of washing hands	Number of subjects	% of subjects
1 time per day	5	1.1
2 times per day	14	3.1
3 times per day	35	7.8
4 times per day	48	10.7
5 times per day	95	21.2
6 times per day	52	11.6
7 times per day	16	3.6
8 times per day	26	5.8
9 times per day	5	1.1
10 times per day	85	19.0
11-20 times per day	52	11.6
21-30 times per day	10	2.2
31-40 times per day	1	0.2
41-50 times per day	1	0.2
50+ times per day	1	0.2
Don't wash hands	2	0.44

Table 8
Use and Co-use statistics for all three air care products according to SUPERB data.

Consumer Type	(% of subjects)				
	All subjects	Males	Females	18–54	55+
Non-consumers	24.7	26.1	24.4	25.2	23.6
Aerosol air freshener	46.6	47.7	46.4	44.2	52.8
Scented candle	50.7	40.9	53.3	51.9	48.0
Plug-in air freshener	23.1	22.7	23.2	25.2	18.1
Plug-in air freshener and aerosol air freshener	5.9	4.5	6.3	7.1	3.1
Scented candles and aerosol air freshener	17.8	18.2	17.8	16.5	21.3
Plug-in air freshener and scented candle	5.0	5.7	4.9	6.1	2.4
Scented candles, aerosol air freshener and plug-in air freshener	8.2	4.5	9.2	8.4	7.9

Table 10
Usual product used to wash hands according to BodyCare survey.

Usual Product Used to Wash Hands	Number of subjects	% of subjects
Bar soap only	55	12.3%
Bar soap and liquid hand soap, but mostly bar soap	41	9.2%
Liquid hand soap only	232	51.8%
Bar soap and Liquid hand soap, but mostly liquid hand soap	77	17.2%
Bar soap and liquid hand soap equally	14	3.1%
None of the above	29	6.5%

excluded from the Phase 2 Creme RIFM model. Non-consumers were excluded due to ambiguity in understanding survey responses. This results in the model being more conservative as the assumption is therefore that all consumers use soap.

3.2. Analysis of phase 2 habits and practices database

The integrated SUPERB and BodyCare data, was assessed for discrepancies compared to the raw data.

It was found that the use statistics remain very similar between the raw data and when integrated of, thus indicating that the simulation method was robust (Table 11). According to the Kantar data, 46.7% of survey participants used bar soap for showering/bathing, however with the integration of the simulated bar soap (hand washing) users (41.3%) from the BodyCare data, the total bar soap users increased to 64.6%. Moreover the percent of consumers who use both bar soap and liquid hand soap was 50.6%, and importantly the percent of total soap users (bar or liquid soap) was 95%.

An analysis of the raw SUPERB survey product use data and the simulated data showed some discrepancies in terms of the percentage of product users (Table 12). It was found that there was a difference between percent of raw and simulated aerosol air freshener consumers due to the fact 42% of spray consumers in the SUPERB survey use sprays less than 5 times a month, leading to low probability of use over a week. A larger discrepancy between raw and simulated scented candles occurred since 77% of candle consumers use them less than 5 times a month according to the SUPERB survey. Therefore, there was a good chance that the simulated 7 day usage diary did not capture all the use events throughout the simulated week, producing what appeared to be infrequent users of the product. Importantly, these discrepancies were not flaws in the simulation methodology, but rather a result of its randomness and as such were to be expected. Finally, there was almost no difference between the percentages of plugin users from the raw and simulated data. This was due to the assumption that an air freshener plugin user was continuously exposed over the survey period, hence the simulated number of consumers did not change for a given simulated week.

3.2.1. Frequency of use in phase 2 habits and practices database

In the Kantar survey data each product usage event was recorded by each subject for a period of 7 consecutive days. The weekly frequency of use was then calculated for each subject by simply counting the number of usage occasions during the survey period. The frequency of use of each of the soap and air care (excluding plug-in fresheners) products was calculated in this manner for each of the 36,446 subjects. Subjects were also grouped by age, gender and country to further analyse frequency of use patterns for the separate demographic groups.

The distribution of ‘frequency of use’ was represented in a density plot, described in an earlier study (Comiskey and AA, 2015). Together with the density plots are the summary statistics for the distributions; Number of subjects (*N*), average frequency of use, per week (*Mean*), and standard deviation in the distribution (*Stdev*). Note the distributions shown only represent the usage patterns of consumers (i.e. subjects who used the product at least one time during the survey period). In addition, some distributions are multi-modal so the mean may not be always a relevant statistic to use when estimating population exposure.

The modes of the frequency of use distributions indicate the most popular usage habits and can be seen as peaks in the density plots. There was a distinct bi-model plot for all users (EU and US) of hair spray; which indicates a usage pattern of approximately once a week and seven times a week (Fig. 2a). However, a higher number of EU subjects tended to use hair spray once a week compared to seven times a week, whereas the opposite was found for US subjects.

The frequency of use for hair spray was clearly bi-modal for female users, but multi-modal for males (Fig. 2). For females, the main peaks are at once and to a lesser extent, seven times per week with an almost flat distribution between these usage frequencies. For males, the highest peak was at seven times per week. However, it should be noted that there were significantly less male subjects who use hair spray, than female subjects.

The modal plot for soap products showed very definite spikes at intervals of seven i.e. 7, 14, 21, 28, 35, 42, 49 and so forth (Fig. 2c). These intervals correspond to hand washing once a day, twice a day, three times a day and so forth. These spikes were a result of the assumption that a subject in the BodyCare survey washes their hands the same number of times every day during the week. As a result the hand washing frequency per week tended to be in multiples of seven. It can be seen that there was a spike of liquid hand soap usage at 70 times per week which corresponds to ten times a day.

For bar soap it was found that there was a spike at seven times a week, indicating frequency of use of once a day, which was likely to be as a consequence of bar soap being used as part of daily showering/bathing. Definite spikes were also found at intervals of seven times a week, similar to the liquid hand soap usage.

Table 11
Use, co-use and non-use statistics for soap products based on survey simulations.

Consumer Type	Hand soap consumers in BodyCare survey (%)	Soap (all types) consumers in Phase 2 database (%)
Liquid hand soap	81	80.5
Bar soap	41.3	64.6
Both bar soap and liquid hand soap	29.2	50.6
Non-consumers	6.5	5.0

Table 12
Comparison of use and non-use statistics based on survey simulations between original SUPERB survey and the 7 day Phase 2 habits and practices diary-style database.

Consumer type	% of consumers in SUPERB survey	% of consumers in Phase 2 database
Plugin air freshener	23.1	23.2
Aerosol air freshener	46.0	34.5
Scented candles	50.7	19.2
Non-consumers	13.0	42.8

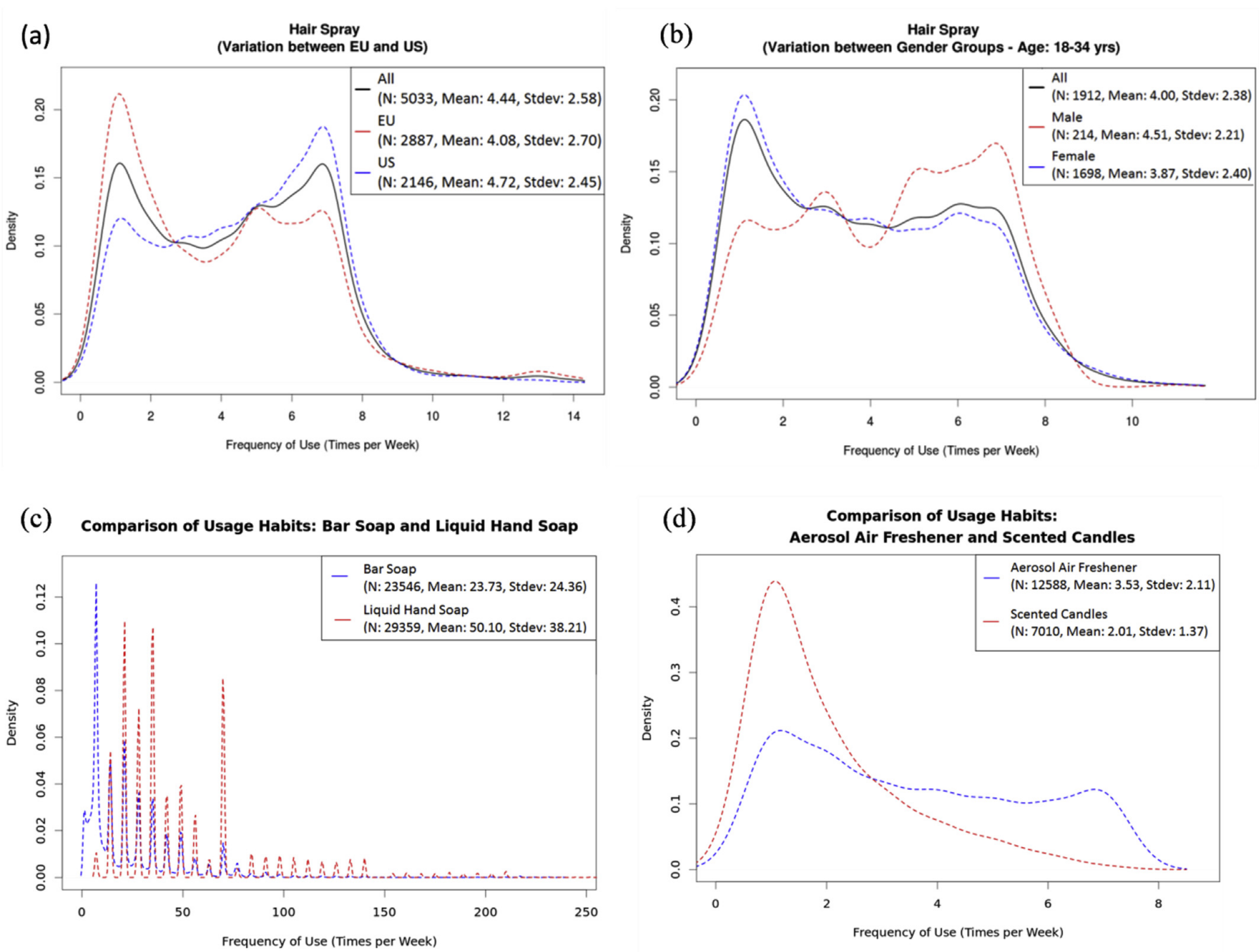

Fig. 2. Comparison of product usage habits for all subjects in the form of density plots: a) hair spray between EU and US, b) hairspray between males and females age 18–34 years, c) bar soap and liquid hand soap, and d) aerosol air freshener and scented candles.

The frequency of use for scented candles peaked at once a week, whereas aerosols air fresheners displayed a bi modal distribution with peaks at one and seven times a week (Fig. 2d). Plugin air freshener users are not shown as it was assumed that if a subject was a user then they use them every day (seven times per week).

3.2.2. Co-use and non-use statistics

To express co-use and non-use patterns, a co-use combinations table was used, similar to that used in previous aggregate exposure studies (Cowan-Ellsberry and Robison, 2009; Comiskey and AA, 2015). For each subject, the combination of products that they use was determined (over the course of the survey). A (weighted) sum was calculated for every product combination observed by summing the total number of co-use events for a given combination of products, and calculating the percentage of this number to the total of all events (thereby giving what fraction of events contain a given set of products). The combinations were listed in decreasing order of popularity within the population. The 20 most popular product co-use combinations are shown in Table 13, where it can be seen that deodorant roll-on, toothpaste, shampoo, bar soap, liquid hand soap were most regularly co-used by subjects. Interestingly, the first 20 most popular consumption combinations are used by only 5.13% of the population.

The 20 most popular product category co-use combinations are shown for the total population in Table 14. The most popular combination (8.65%) was deodorant, oral care, shower products,

Table 13
Top 20 product co-use combinations (per subject).

Product Combination	% of Subjects	% Cumulative
Deodorant roll-on, toothpaste, shampoo, bar soap, liquid hand soap	0.84	0.84
Deodorant roll-on, toothpaste, shampoo, bar soap, liquid hand soap, aerosol air freshener	0.43	1.27
Deodorant spray, toothpaste, shampoo, bar soap, liquid hand soap	0.34	1.62
Deodorant spray, toothpaste, shampoo, shower gel, bar soap, liquid hand soap	0.29	1.91
Toothpaste, shampoo, bar soap, liquid hand soap	0.27	2.18
Deodorant roll-on, toothpaste, shampoo, shower gel, bar soap, liquid hand soap	0.25	2.43
Deodorant roll-on, toothpaste, shampoo, shower gel, liquid hand soap	0.24	2.67
Deodorant roll-on, toothpaste, shampoo, bar soap	0.24	2.91
Deodorant roll-on, toothpaste, aftershave, shampoo, bar soap, liquid hand soap	0.24	3.15
Deodorant roll-on, toothpaste, shampoo, bar soap, liquid hand soap, plug-in air freshener	0.21	3.36
Deodorant roll-on, toothpaste, shampoo, bar soap, liquid hand soap, scented candles	0.20	3.55
Deodorant roll-on, toothpaste, shampoo, rinse-off conditioner, bar soap, liquid hand soap	0.20	3.75
Toothpaste, shampoo, shower gel, bar soap, liquid hand soap	0.20	3.95
Deodorant spray, toothpaste, shampoo, bar soap, liquid hand soap, aerosol air freshener	0.19	4.14
Deodorant roll-on, toothpaste, bar soap, liquid hand soap	0.18	4.31
Toothpaste, shampoo, bar soap, liquid hand soap, aerosol air freshener	0.18	4.49
Toothpaste, bar soap, liquid hand soap	0.17	4.65
Deodorant roll-on, toothpaste, mouthwash, shampoo, bar soap, liquid hand soap	0.16	4.81
Deodorant spray, toothpaste, shampoo, shower gel, liquid hand soap	0.16	4.97
Deodorant roll-on, toothpaste, shampoo, rinse-off conditioner, shower gel, liquid hand soap	0.16	5.13

Table 14
Top 20 product category co-use combinations (per subject – Total Population).

Product Combination	% of Subjects	% Cumulative
Deodorant, oral care, shower products, soaps, air care	8.65	8.65
Deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturizers, soaps, air care	6.56	15.20
Deodorant, oral care, shower products, soaps	6.11	21.32
Deodorant, oral care, hydro-alcoholics, shower products, soaps, air care	5.70	27.02
Deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturizers, soaps	5.12	32.14
Deodorant, oral care, hydro-alcoholics, shower products, soaps	4.08	36.22
Deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, soaps, air care	3.78	40.00
Deodorant, oral care, cosmetic styling, shower products, soaps, air care	3.14	43.15
Deodorant, oral care cosmetic styling, hydro-alcoholics, shower products, soaps	2.88	46.02
Deodorant, oral care, cosmetic styling, shower products, moisturizers, soaps, air care	2.50	48.52
Deodorant, oral care, hydro-alcoholics, shower products, moisturizers, soaps, air care	2.45	50.97
Deodorant, oral care, cosmetic styling, shower products, soaps	2.27	53.24
Body lotion, deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturizers, soaps, air care	2.23	55.47
Deodorant, oral care, shower products, moisturizers, soaps, air care	2.09	57.56
Oral care, shower products, soaps, air care	2.02	59.57
Deodorant, oral care, cosmetic styling, shower products, moisturizers, soaps	2.00	61.57
Deodorant, oral care, hydro-alcoholics, shower products, moisturizers, soaps	1.92	63.49
Body lotion, deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturizers, soaps	1.77	65.26
Deodorant, oral care, shower products, moisturizers, soaps	1.67	66.93
Body lotion, deodorant, oral care, cosmetic styling, shower products, moisturizers, soaps, air care	1.61	68.54

soaps and air care. This meant that an estimated 8.65% of males and females EU and US region use a combination of the aforementioned products.

4. Discussion

The purpose of the present study was to expand the Phase 1 Creme RIFM aggregate exposure model by the addition of air care products, soaps and hairspray as well as to allow exposure via the respiratory route to be estimated. This required merging habits and practices data from three different sources to create a probabilistic model, requiring an algorithm to simulate user consumption to merge with the Phase 1 database.

Hand washing (liquid and bar soap) data were simulated based on a subset of 448 US subjects aged 18–64 to give a likely frequency and co-use per day. In the present model it was assumed that the usage habits were equal for seven days in a week. However, exact day-to-day repetition is unlikely in reality and could lead to an under or overestimation of exposure. Furthermore, the approximation of handwashing frequency per day, which was based on recollection rather than a detailed hour-by-hour recording in a diary, could be subject to error. Moreover, it was shown that there was a noticeable increase in hand washing frequencies at five and 10 times a day, in comparison to any other frequency (*cf.* Table 9 and Fig. 2c). It was possible that the BodyCare participants chose a round number such as a"10 times per day" or a middle/median number such as "5 times a day" in comparison to any other frequency, when asked how often they washed their hands. This bias towards a round or median number may also lead to an over or underestimation of exposure. Furthermore, the co-use was based on a qualitative description, which was approximated to a quantitative description, thus increasing the uncertainty of the model and thus exposure. Nevertheless, it is believed that the approach employed (supplementing the Phase 1 database with simulated hand washing data) provides a realistic estimation of hand washing exposure, as it simulates exposure events on the individual level based on the variability of reported data rather than assuming worst-case or average estimates.

To model exposure to air care products, it was necessary to simulate a survey of monthly product use as a seven day diary to coincide with the Phase 1 habits and practices survey. Therefore, it was assumed that the monthly use of air care products, including scented candles and aerosol air fresheners, could be allocated into random days of a month with no particular weighting given to specific day or week. This led to a situation where users that reported use of air-care products became infrequent users when integrated with the seven-day diary format of the Phase 1 database, resulting in a reduction in percentage of consumers reported using products (Table 12). Although this appears to lead to an underestimation of exposure, it was in fact a realistic representation. For example, if a subject in the SUPERB survey indicated that they used a scented candle once a month, then the chance of them using the product in any given week of a month was 25% (assuming exactly four weeks in one month). As such, in the proposed simulation approach, the single use could be allocated to any random day in a month, and in any random week. Thus, there was only approximately a 25% chance that this single use event will be captured in the Phase 2 habits and practices database.

According to the EPHECT study, 26% of European survey participants use combustible air fresheners (scented candles, incense or heated oils) at least once in the last 6 months prior to the survey (Johnson and Lucica, 2012). The higher percentage of candle users according to the SUPERB study (50.7%, Table 8) may have been due to ambiguity in “plain or scented candles” product description option. Despite this, it was also possible that the a ‘plain candle’ may have been scented unbeknownst to the SUPERB survey participant. Also, SUPERB was a US based study, so in reality differences may exist between the US and EU population. Regardless, the ambiguity may lead to a more conservative exposure estimation in the model. Conversely, the percentage of consumers using plugin fresheners in the SUPERB survey were maintained when simulated and integrated with the Phase 2 habits and practices database (Table 12). This was to be expected as the users were assumed to be daily users. This was a reasonable assumption given that plugin fresheners tend to be used on a continuous basis when used.

In the present model it was assumed that the habits and practices data from surveys conducted in the US (BodyCare and SUPERB) were representative of Europe too. For air care products, it was assumed that the US Californian population represents the entirety of the US population and extends to EU population. This was considered reasonable given that the total percent of product users were equal or similar between EU and US populations (Table 1). However, this did not indicate EU-US equivalence in product co-use or frequency of use between genders or age groups. As such there was uncertainty in the model due to this assumption, which can only be improved with further data.

With regards to the soap hand washing survey data (BodyCare), it was assumed that 448 adult subjects (age 18–64) in US were representative of the wider US population. Importantly, a study conducted on hand washing by the US EPA (EPA, 2011), specifically for US adults ($N = 2973$, age 18–64), showed similarity in hand washing habits with the BodyCare study (Table 15, Fig. 3). Thus, the BodyCare survey data was considered representative of the wider US population. With regards to comparability with the EU population, according to the EU Technical Guidance Document the frequency of hand washing with bar soap was 3–6 per day (EU TGD, 2003), which was comparable to the peak frequency of 3–5 times a day in both EPA and BodyCare studies.

The amount per use data for soaps (bar and liquid) were based on Danish studies, and assumed applicable for the rest of EU and US. This assumption was reasonable considering the fact that liquid hand soap in particular are produced in discrete measured doses and thus the likely use in Denmark will be similar across the wider EU and US populations. More over, it was assumed that the bar soap

Table 15
Comparison of hand washing habits between EPA and BodyCare survey study participants.

Number of hand washing times/day	(EPA study)		(BodyCare study)	
	N	*%*	*N*[a]	*%*
0	7	0.2	2	0.4
1–2	131	4.6	19	4.2
3–5	1029	35.8	178	39.7
6–9	760	26.4	99	22.1
10–19	640	22.2	137	30.6
20–29	168	5.8	10	2.2
30+	143	5	3	0.7
Total	2973	100	448	100

[a] Numbers of subjects in the BodyCare survey were aggregated into hand washing times/day ranges to coincide with the EPA study.

hand washing amount per use data was based upon liquid hand soap using a scaling factor. This scaling factor ensured the mean amount per use of bar soap conformed to the EU average according to the EU Technical Guidance Document (EU TGD, 2003).

The distributions of amount per use data for aerosol air fresheners and plugin fresheners, based on US data, should provide a reasonable representation of product use in EU. The use of a single point value of amount per use data for the scented candles does not contribute to a probabilistic distribution which is the most desirable approach to use. However, once more data become available, distributions may be added for random sampling.

Finally, it was assumed that the amount per use data for aerosol hair spray, based on a US study on females (Loretz et al., 2006) was applicable for US males and EU males and females. Although amount per use data for Dutch adults has been collected for hairspray (Biesterbos et al., 2013), the US data was acquired from a more controlled environment where measurements were taken before and after product use. Lastly, the US data had a higher average amount use per day (mean = 3.57 g/day) in comparison to the Dutch study (mean = 0.4 g/day). Consequently the US data would provide a more conservative exposure estimation.

In this study, the inhalation exposure was based on the RIFM 2-box model where the inhalation exposure scenarios had the same conditions for each product type, i.e. volume of room/breathing zones, exposure duration in each zone, air exchange rates, emission durations, emission rates, and inhalation rate. As a result the inhalation exposure fractions were based on the default input values for each inhaled product in the 2-box model. Nevertheless,

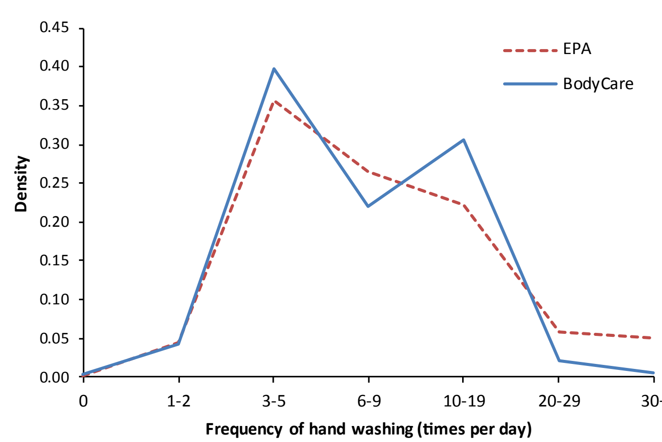

Fig. 3. Density plots of hand washing habits between subjects in SUPERB and BodyCare studies.

this was a reasonable assumption given that the default settings in the 2-box model were based on the data from the peer reviewed literature (Bremmer et al., 2006; EPA, 2011), which are considered conservative default values.

In this study, body spray was assumed to have a dermal retention and penetration of 100% with no exposure occurring via the inhalation route. From the point of view of systemic toxicity, this is a more conservative assumption given that a significant proportion of the aerosol in the air tends to be exhausted from a room/home and because the amount inhaled is regulated by an individual's breathing rate. However, this may not be the case if considering a respiratory endpoint. Note that the focus of this publication is on how the model was developed, as well as a critical evaluation of the supporting data sources. For a detailed study on the performance and consequences of the model, the reader is directed towards (Safford et al., 2017).

4.1. Future work

A concurrent publication shows how use levels of fragrance data can be inputted into the model to estimate fragrance exposure (Safford et al., 2017). There is scope to develop the model further to analyse fragrance exposure in laundry and household cleaning products, especially given the multiple routes of exposure (dermal, oral residue ingestion and inhalation). Moreover, an important component missing in the model is the occurrence or presence probability of fragrance materials in the products, where it was assumed that the fragrance was always present; which is a highly conservative, unrealistic assumption. An understanding of the actual likelihood of a fragrance being present in product will lead to a more refined aggregate exposure estimate. Another broader issue that merits investigation is the applicability of short-term (in this case seven-day) diaries to assess infrequent exposures. This is somewhat highlighted by the fact that some modelling assumptions were required to integrate data on monthly basis from the SUPERB survey to the seven-day structure of the Creme RIFM database. This issue has been addressed in the food domain, and this study may benefit from the application of similar techniques used to analyse short term dietary surveys (Slob, 2006). Furthermore, the expansion of the habits and practices data to include more EU countries will lead to a more accurate representation of the wider EU population. Lastly, the addition of habits and practices data for subjects aged less than 18 will allow a modelling of exposure to young adults, with the possibility to extend to younger ages (<13 yrs).

Conflict of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Transparency document

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