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Novel database for exposure to fragrance ingredients in cosmetics and personal care products

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ABSTRACT

Exposure of fragrance ingredients in cosmetics and personal care products to the population can be determined by way of a detailed and robust survey. The frequency and combinations of products used at specific times during the day will allow the estimation of aggregate exposure for an individual consumer, and to the sample population. In the present study, habits and practices of personal care and cosmetic products have been obtained from market research data for 36,446 subjects across European countries and the United States in order to determine the exposure to fragrance ingredients. Each subject logged their product uses, time of day and body application sites in an online diary for seven consecutive days. The survey data did not contain information on the amount of product used per occasion or body measurements, such as weight and skin surface area. Nevertheless, this was found from the literature where the likely amount of product used per occasion or body measurement could be probabilistically chosen from distributions of data based on subject demographics. The daily aggregate applied consumer product exposure was estimated based on each subject's frequency of product use, and Monte Carlo simulations of their likely product amount per use and body measurements. Statistical analyses of the habits and practices and consumer product exposure are presented, which show the robustness of the data and the ability to estimate aggregate consumer product exposure. Consequently, the data and modelling methods presented show potential as a means of performing ingredient safety assessments for personal care and cosmetics products.

1. Introduction

Comprehensive habits and practices data on the consumption of cosmetic and personal care products between different subject demographics is necessary for safety assessments. Specifically, data on product use, co-use and non-use provides an accurate portrayal of the exposure that subjects in the population are exposed to over a time period. Currently for substances in cosmetics and personal care products, European regulations require that an evaluation of exposure to the substance be carried out (Commission, 2009) and additionally requires overall exposure and vulnerable subpopulations be evaluated for substances that are carcinogenic, mutagenic or toxic for reproduction.

Current methods used to estimate aggregate exposure to fragrance ingredients in cosmetics is based on deterministic summation of individual consumer product exposures, without considering co-use or population variability, according to the SCCS Notes of Guidance (SCCS, 2012). Typically, high end (upper percentile) exposures of each product are summed to provide the aggregate exposure. This approach overestimates exposure to cosmetics and will lead to overly conservative safety assessments.

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At present there is a lack of co-use data available in the literature that will allow an accurate estimation of aggregate exposure to members of the population. Population-based studies involving cosmetic diaries sourced from market survey companies have been conducted previously (Hall et al., 2007, 2011; McNamara et al., 2007). The approach outlined in this study is an extension of this approach, but covers more product categories, a larger number of consumers and more regions (including Europe and the United States). On-line survey data that examines co-use has been used in the past to analyse air care exposure, but these were questions based on use per month (Moran et al., 2012). Other surveys on exposure of products to children has been conducted which can be used to determine product consumption per unit body weight, however, product co-use was not recorded (Gomez-Berrada et al., 2013).

In order to estimate aggregate exposure to individual ingredients/fragrances present in multiple product categories at varying concentrations, a dataset is required that details how different product categories are used in different combinations by a population of consumers. In addition, there needs to be an understanding of concentration levels of the individual ingredients/fragrances in these products. The product use data exists in market surveys performed by market research companies such as Kantar Worldpanel, who routinely survey consumer habits and practices. There is still however a need for a detailed analysis of the co-use of cosmetic and personal care products used during the day, over several days, by different demographics in the population, and amounts of product used per application. This will allow the calculation of aggregate exposure to cosmetic and personal care products in a representative population. The use levels of the individual ingredients/fragrances in products were obtained by surveying member companies and data in the peer-reviewed literature (Cowan-Ellsberry and Robison, 2009).

It is the aim of the present study to develop an aggregate exposure model that is based on survey data to accurately estimate aggregate exposure to fragrance ingredients in cosmetic products. To do this, we combine data from a cosmetics market research survey and product amount usages data from the literature, both of which are cross referenced with the survey subjects' demographics. Then, we probabilistically estimate bodyweights and surfaces areas based on subject demographics to estimate applied consumer product exposure per unit bodyweight and per unit surface area.

2. Methods

The calculation of applied consumer product exposure to cosmetics requires the following quantifiable components: (1) frequency of product use per day, *F*, (2) amount of product used per occasion, *A*, and (3) product retention, *R*. The daily exposure, *DE*, (g/day) of a single product can be described mathematically by the following equation

$$DE = F \times A \times R \tag{1}$$

To calculate the exposure to a fragrance ingredient in a product, there are two concentration values that must be known; the percentage concentration of a specific fragrance ingredient in a mixture, C_1, and the concentration of the ingredient mixture added to a product, C_2. The multiplication of these concentrations factors will provide the concentration of a fragrance ingredient in a product, *C*. With this information the daily exposure to a fragrance ingredient in a single product, *DE*, (μg/day) can be calculated

$$DE = F \times A \times R \times C \tag{2}$$

There are two other types of daily exposure that may be calculated; exposure per unit body surface area, *SA*, or per unit bodyweight, *BW*, each with their own safety assessment application. The *DE* of a fragrance ingredient from one product per unit bodyweight (μg/kg bw/day), of the subject can be written as

$$DE = \frac{F \times A \times R \times C \times P}{BW} \tag{3}$$

where *P* refers to a dermal penetration (or absorption) factor, and so, daily exposure per unit *SA* (μg/cm^2/day) from one product to a specific application site can be written as

$$DE = \frac{F \times A \times R \times C \times P}{SA} \tag{4}$$

The aggregate daily exposure, per unit *BW* or per unit *SA*, for an individual subject can be sought by adding up the exposures from each product, thus

$$DE_{\text{Agg}} = DE_{\text{Product\_1}} + DE_{\text{Product\_2}} + \ldots + DE_{\text{Product\_N}} \tag{5}$$

The equations above calculate the fragrance exposure for a single person. The population daily exposure, *PDE*, is usually reported as a statistic (typically a relatively high percentile, such as the 95th), of the individual exposures. Therefore we can write

$$PDE = \text{Stat}(DE_1, DE_2, \ldots, DE_M) \tag{6}$$

Hence in the proceeding sub sections, the data sources that will be inputted into the above equations (Eqs. (1)–(4)) will be investigated, with the exception of fragrance ingredient and mixture concentrations, which is dealt with in a concurrent publication (Safford et al., 2015). Also there is an investigation of the subjects who consume a range of cosmetic and personal care products for the calculation of aggregate exposure on a per subject level (Eq. (5)) and statistics based on a sample population (Eq. (6)).

2.1. Study population

In the present study, to calculate aggregate exposure to subjects from a large sample population, subject data was obtained from the Kantar Worldpanel Usage Toiletries and Cosmetics Database. This database, typically used for marketing research purposes, contains habits and practices data on subjects who use all toiletries and cosmetics categories from The United States (hereafter referred to as US) and Europe (hereafter referred to as EU). Subjects were included in the surveys based on their age (11–74), gender, sample representative of the region, employment status and whether they were habitual users of all personal care (toiletries and cosmetic) products, brands and categories. For the purposes of the present study, only subjects from the US and EU (including France, Germany, Great Britain and Spain) from the age of 18 upwards were analysed; culminating in a total of 36,446 subjects. Importantly these European countries represent over 60% of the EU15 population, and as such were considered to be representative.

The subjects were categorised based on their age, gender and country. The subjects' ages were further subcategorised into five age groups; 18–24, 25–34, 35–49, 50–64 and 65+. Also, the subjects from France, Germany, Great Britain and Spain were grouped together into the EU region, meaning that the subjects were either from the US or EU. Lastly, the subjects were further grouped based on their gender; male and female.

The Kantar database contains anonymised data on the subjects themselves; however, the relevant data in the present study was age, country, gender and statistical weighting. The weighting factor is used to compensate for the fact that the demographics within sample number of subjects in the database may not represent the demographics in the entire population. Hence, the weighting factor ensures that each demographic group is equally represented statistically. This is necessary for calculating statistics for the "whole population", used later in this study. The number of subjects in the various demographics is shown in the below, where imbalances between demographics is noticeable (Table 1).

Consequently, the subjects are weighted appropriately to account for any imbalances in the demographic proportions. For example, if a particular demographic group is underrepresented in the survey – then the surveyed subjects can be assigned a greater statistical weight to account for the fact that each of them is representing a greater proportion of the total population in that country.

2.2. Data collection

The subjects of the Kantar survey were required to fill out a characteristics questionnaire which includes age, country, gender and other physical attributes (skin type, hair length etc.). The subjects also complete a 7 day online diary of the frequency of personal care product use occasions as part of their daily routines and were not provided with products which would invariably lead to a modification of routine. Each subject logs the product that is used during each use occasion including brand and product name, which is chosen from a pre-populated online database to ensure naming consistency. The subjects also log the time of day that the specific product was used (by the hour). Finally, the subjects log the parts of the body that the product was applied to. The body part names were pre-defined; hence the subject would choose the appropriate body part name from a list. The survey data relevant to the products and subjects in the present study were acquired from 1 week diaries that were completed between the years 2007 and 2008 during all weeks of the year.

2.3. Products under investigation

The Kantar Worldpanel Usage Toiletries and Cosmetics Database contain habits and practices data of a wide variety of products. However, for the purposes of the present study, 43 'survey product' types were chosen from the database to be included in the present analysis/model. The product types were chosen based on three criteria; (1) the products are commonly used on a daily basis by males and/or female consumers, (2) the products are major contributors to fragrance ingredient exposure from personal care and cosmetic products and (3) habits and practices data was available for the products of interest.

The 43 'survey products' were further filtered/sub categorised into 19 higher level 'study product' types (Table 2). The 43 products were grouped as such to allow a simpler interpretation of the consumer product exposure and to ensure that the product sample sizes were sufficiently large to perform robust statistical analyses.

The 19 products were then grouped into 7 categories in order to examine the co-use combinations within each category (Table 2). This categorisation is for the purposes of helping to understand the co-use habits, and also to help in visualising exposure results. The products within each category are similar in nature and habitual use.

Table 1
Number of subjects in survey according to demographics.

Age groups	EU		US	
	Male	Female	Male	Female
18–24	1490	2557	412	1228
25–34	2980	3078	603	1954
35–49	4230	4763	838	2200
50–64	3210	2966	748	1541
65+	560	375	289	424
Total	12470	13739	2890	7347

Table 2
Products defined in the survey which was filtered into products of interest in this study and their categorisation.

Product category	Study product definition	Survey product definition
Body lotion	Body lotion (mass market) Body lotion (prestige) Body lotion (other)	Body lotion, body milk, body cream, body butter, body firming/toning moisturiser, other body moisturiser, general purpose moisturiser
Deodorant	Deodorant spray	Deodorant spray(i.e. antiperspirant)
	Deodorant roll-on	Roll-on, stick, cream, gel
	Body spray	Body spray (not antiperspirant)
Oral care	Toothpaste	Toothpaste
	Mouthwash	Mouthwash
Cosmetic styling	Lipstick	Lipstick
	Liquid makeup foundation	Liquid make up foundation
	Hair styling	Leave in conditioner, mousse, total gel, gel, gel spray, wax, cream, putty, setting lotion, gloss/serum
Hydro-alcoholics	Eau de toilette	Eau de toilette
	Eau de parfum	Eau de parfum
	After shave	Splash-on, aftershave, cologne
Shower products	Shower gel	Shower gel
	Shampoo	Shampoo
	Rinse-off conditioner	Rinseoff conditioner
Moisturisers	Face moisturiser	Daily face moisturiser, SPF moisturiser, tinted face moisturiser, night face moisturiser, anti-ageing face moisturiser, other face moisturiser
	Hand cream	Hand moisturiser Hand & Nail Moisturiser

It should be noted that the body lotions were further broken down by 'mass market', 'prestige' and 'other'. The reason for this was due to the tendency of prestige brands to have a higher fragrance concentration in comparison to mass market brand body lotions, and because they may be used less frequently. The authors separated all the brand names for body lotion found in the Kantar Database based on expert judgement, into their respective sub categories. In the case where no distinction between a brand that was 'mass market' or 'prestige' could be made, they were categorised as 'other'.

2.4. Product application sites

To estimate exposure to a specific application site, or to the total body for that matter, it is necessary to know on which site of the body subjects in the survey applied their products. In the Kantar surveys, subjects were asked to record the application site at each usage event for many of the products. For body lotion, body spray, deodorant spray, deodorant roll-on, eau de parfum and eau de toilette, panellists in both the US and EU regions were presented with the option to select the application site(s) on which they used the product. For aftershave, face moisturiser and hand cream, only panellists in the EU region were asked to record application site. For the remainder of the products (hair styling, lipstick, liquid makeup foundation, mouthwash, rinse-off conditioner, shampoo, shower gel and toothpaste) the option to include application site information was not made available for either US or EU region panellists.

Since panellists in the EU region were presented with slightly different application site options to those in the US region, it was necessary to define a set of application sites which was consistent with the two data sources. The options in the US and EU regions were therefore rationalised to a list of 18 application sites (Table 3).

For products where the application site was recorded by EU region panellists only, corresponding data on application sites were used in the model for US region panellists. For those products where no application site was recorded (EU or US regions), application sites have been assumed based on product type.

Finally, according to model assumptions shown above and the consumer survey data, we can compile a table describing the products were applied to specific application sites (Table 4).

2.5. Amounts used

The amount per use of the products is not included in the Kantar survey, consequently, these data are obtained from additional sources (Table 5). Amount per use data for EU subjects were collected by COLIPA (now Cosmetics Europe) (Hall et al., 2007, 2011). Data for US subjects were collected by CTFA (now the Personal Care Products Council) (Loretz et al., 2005, 2006, 2008). Amounts data on hydro alcoholic products was obtained by Tozer et al. (2004). This study involved measuring the number of actuations (sprays) per use, as well as the average amount of product used per actuation. In various cases, summary statistics and fitted distributions and/or distributions of discrete datum points were provided.

The amounts per use data was relevant for specific regions (EU and/or US) and/or were gender specific. Hence, each subject in the Kantar survey would be paired with amount per use data that was based on their demographic, which could be randomly sampled from.

It should be noted that the amounts data for deodorant spray, body spray, toothpaste, mouthwash, hair styling, aftershave and hand cream is from a European study only, whereas, rinse-off conditioner is from a US study only. As such the EU amount per use data was mapped to the US subjects and vice versa.

2.6. Product retention and dermal penetration

The retention factor is a measure of how much of the cosmetic product will be retained after use and defines the amount of the individual ingredient remaining on the skin. The retention factors applied in the model are shown in Table 6, and are taken from Api et al. (2008). For deodorant spray, it is assumed that 23.5% of the product which leaves the product container, is applied to the underarms (Steiling et al., 2012).

For other spray products (body spray, eau de parfum, eau de toilette), it is assumed that 100% of the product which leaves the product container, is applied to the skin. This is a conservative assumption, as it is likely that an amount of the product will escape into the air. Inhalation of these spray products was not considered at this time.

The dermal penetration factor, P, depends on a number of factors including body part, skin type, product type, and chemical type. In this study, a conservative dermal penetration factor of 100% will be used for products applied to the skin for the calculation of exposure per unit bodyweight.

2.7. Body measurements data

To calculate the dose per unit skin surface area and per unit bodyweight, it was necessary to incorporate the surface area of the relevant body parts and bodyweight for each subject, respectively. However, these data were not available for the subjects in the Kantar Worldpanel surveys. It was necessary therefore to introduce these measurements indirectly, by integrating data from alternative data sets. Importantly, the surface area of certain body parts can be estimated for an individual using that person's bodyweight and height. Bodyweight and height data for 8861 US subjects is available from the 2007 to 2008 NHANES survey (Centers for Disease Control and Prevention (CDC) & National Center for Health Statistics (NCHS), 2008). Hence, bodyweight and height data for each of the 10 demographic groups (Table 1) in the Kantar data were determined probabilistically, by constructing the relevant distribution from the NHANES data. The bodyweight and height for each Kantar subject in the corresponding demographic group, is then represented by this distribution.

Unfortunately, a corresponding data set with paired bodyweight and height data for the EU countries of interest could not be identified. The bodyweight and height for the EU subjects was therefore modelled on the NHANES distributions. Appropriate scaling factors were incorporated to adjust for inter-country variations. These were defined by comparing average bodyweight and height values for males and females in each of the 4 EU countries (France, Germany, Spain, and Great Britain; Table 7) with the corresponding average values for the US (from NHANES). These scaling factors are shown in Table 8 and Table 9.

Table 3
List of body parts.

Body part	Additional comments
Scalp	
Face	Does not include eyes, lips, mouth or behind ears
Eyes	The eyelid and surrounding skin
Lips	
Mouth	Does not include the lips
Neck	Does not include behind ears
Behind ears	
Chest	Does not include underarms or stomach
Stomach	
Back	Does not include underarms
Underarms	
Arms	Includes shoulder, forearm and upper arm Does not include wrists, hands, palms or underarms
Wrists	
Back of Hand Palms	Does not include palms and wrists
Intimate parts	
Legs Feet	Includes bottom, thighs, and calves. Does not include feet

2.8. Application site surface areas

Following Api et al. (2008), dermal exposure is measured as the dose per unit area ($\mu g/cm^2$). In order to calculate these data it is necessary to incorporate the surface area of each application site on which the product was used. Body surface area is calculated from bodyweight and height data using the Dubois formula (Dubois and Dubois, 1916)

$$SA = a \times W^b \times H^c \tag{7}$$

where W is bodyweight, H represents height and a, b and c are experimentally determined constants. These constants were obtained from the EPA Exposure Factors Handbook (Office of Research and Development National Center for Environmental Assessment U.S. Environmental Protection Agency, 2009). The body surfaces areas that calculated based on the Dubois formula (Eq. (6))

Table 4
Application site exposure to product.

Product	Scalp	Face	Eyes	Lips	Mouth	Neck	Behind ears	Chest	Stomach	Back	Underarms	Arms	Wrists	Hands	Palms	Intimate parts	Legs	Feet
Body lotion (mass)	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Body lotion (prestige)	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Body lotion (other)	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Body spray	–	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Deodorant roll–on	–	–	–	–	–	✓	–	✓	✓	✓	✓	✓	✓	✓	–	✓	–	–
Deodorant spray	–	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Toothpaste*	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–
Mouthwash*	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–
Lipstick*	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Liquid makeup foundation*	–	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hair styling*	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–
Aftershave	✓	✓	–	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	–	–
Eau de parfum	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Eau de toilette	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Rinse-off conditioner*	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–
Shampoo*	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	–	–	–
Shower gel	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Face moisturiser	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hand cream	✓	–	–	–	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

* Products with assumed application sites.

Table 5
Data sources for amount per use.

Product	Publication	Additional information
Body lotion (mass/prestige/ other)	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
	Loretz et al. (2005)	Summary statistics and distribution fit: average amount per use 360 subjects: US, F, aged 19–65
Deodorant spray	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
Deodorant roll-on	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
Body spray		Amount per use, approximated as deodorant spray
Toothpaste	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
Mouthwash	Hall et al. (2011)	Empirical data: each subject's average amount per use501 subjects: EU, M/F, aged 17–74
Lipstick	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
	Loretz et al. (2005)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
Liquid makeup foundation	Hall et al. (2011)	Empirical data: each subject's average amount per use501 subjects: EU, M/F, aged 17–74
	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
Hair styling	Hall et al. (2011)	Empirical data: each subject's average amount per use501 subjects: EU, M/F, aged 17–74
Eau de toilette	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
	Tozer et al. (2004)	Amount per use for hydro-alcoholics in adults – data gathered on number of actuations per use ($n > 2000$) and amount per actuation ($n = 212$)
Eau de parfum	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
	Tozer et al. (2004)	(as above for eau de toilette)
Aftershave		Amount per use, approximated as eau de toilette
Shower gel	Hall et al. (2011)	Empirical data: each subject's average amount per use501 subjects: EU, M/F, aged 17–74
	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
Shampoo	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
	Loretz et al. (2006)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 19–65
Rinse-off conditioner	Loretz et al. (2008)	Summary statistics and distribution fit: average amount per use360 subjects: US, F, aged 18–69
Face moisturiser	Hall et al. (2007)	Empirical data: each subject's average amount per use496 subjects: EU, M/F, aged 17–74
	Loretz et al. (2005)	Summary Statistics and distribution fit[a]: average amount per use360 subjects: US, F, aged 19–65
Hand cream	Hall et al. (2011)	Empirical data: each subject's average amount per use501 subjects: EU, M/F, aged 17–74

In the Hall et al., studies, empirical data on each subject's average amount per use as obtained in the studies are used in the model. Since the data were derived from studies conducted in Scotland, scaling factors are applied to represent usage in each EU country. The scaling factors have previously been described by Hall et al. (2007, 2011).

[a] The distribution did not provide a good fit for "face cream" according to the study.

and the constants from EPA Exposure Factors Handbook were total body, head, trunk, arms, hands, legs and feet.

The aforementioned body parts do not match the full list application sites which were specified based on the Kantar data (Table 3). Therefore, other application sites surface areas were taken directly from published data or expert judgement as outlined in Table 10.

No reference values could be found for the surface area of the neck, chest, stomach and back. Together these body parts make up the trunk, as defined in the EPA Exposure Factors Handbook. It was necessary therefore to define the area of these 4 application sites relative to the trunk. The values shown above (neck 10%, chest 25%, stomach 20%, back 30%) are considered reasonable estimates. It is worth noting that:

1. The sum of the values is 85% of the trunk (providing slightly conservative estimate for exposure per unit surface area)
2. Chest and stomach together (45% of trunk) is slightly more than back (30% of trunk)

Lastly, some application site surface areas were based on absolute measurements from the literature (Table 11).

Table 6
Retention factors.

Product	Dermal retention factor (%)	Ingestion factor (%)
Body lotion (mass, prestige, or other)	100	–
Deodorant spray	23.5	–
Deodorant roll-on	100	–
Body spray	100	–
Toothpaste	10	5*
Mouthwash	1	10*
Lipstick	100	–
Liquid makeup foundation	100	–
Hair styling	10	–
Eau de toilette	100	–
Eau de parfum	100	–
Aftershave	100	–
Shower gel	1	–
Shampoo	1	–
Rinse-off conditioner	1	–
Face moisturiser	100	–
Hand cream	100	–

* When determining exposure per person per day, or per unit bodyweight for the oral care products, only the ingestion factor of the product is taken into account (not the dermal retention factors). In this case the ingestion factors used are 10% for mouthwash and 5% for toothpaste as defined in the SCCS Notes of Guidance (SCCS, 2012). The dermal retention factors for toothpaste and mouthwash are only used if calculating dermal exposure to these products (dose per cm^2 skin).

2.9. Simulation of individual and aggregate exposure

The raw data and distributions determined from the data sources were probabilistically combined using Monte Carlo simulation analysis in a software system 'Creme RIFM Model' developed by Creme Global (www.cremeglobal.com). Monte Carlo simulations rely on ranges on possible inputs (amount per use, body weight and height, fragrance ingredient and mixture concentrations) which are randomly selected to conduct enough calculations to produce a distribution of exposure results. This was conducted using Creme Global's state of the art cloud computing system.

A brief overview of the Monte Carlo simulation method to calculate exposure is presented schematically in Fig. 1, and described here:

1. A subject is sequentially chosen from the list of subjects in the Kantar database.
2. The subject is assigned to a demographic group based on gender and age (e.g. male, aged 18–24).
3. A bodyweight and height is assigned to the subject by randomly sampling the distributions for these values corresponding to the demographic group.
4. The use event of each product of interest for that subject is taken from the Kantar database, for each day of the survey.

Table 7
Data source for each EU country of bodyweight and height.

Country	Height data source	Bodyweight data source
France	La taille des homes (Herpin, 2003)	Exposure factors sourcebook for European populations (ECETOC, 2001)
Germany	Mikrozensus – Fragen zur Gesundheit (Statistisches Bundesamt, 2009)	
Spain	The Evolution of Adult Height in Europe(Garcia and Quintana-Domeque, 2006)	
Great Britain	Health Survey for England 2007 (NHS, 2008) The Scottish Health Survey 2008 (Corbett et al., 2009) Welsh Health Survey 2009 (National Centre for Social Research, 2010)	

5. For each product of interest, a usage amount is sampled from the appropriate distribution corresponding to the subject's demographic grouping. The same amount is assumed at each usage event for that subject.
6. A retention factor for each product is applied to the usage amount to calculate the amount that is retained following use.

Then for exposure per unit bodyweight (for exposure per unit surface area, skip to step 12):

7. The total applied consumer product exposure after rinse off or ingestion (g/day) from each product is calculated, for each day of the survey.
8. A fragrance concentration values is sampled from distributions of fragrance in mixture concentration, C_1, and mixture in product concentrations, C_2, to calculate the concentration of fragrance in each product, C, to calculate.
9. Apply a dermal retention factor and penetration factor to calculate the exposure to the concentration of fragrance ingredient (μg/day).
10. Dividing by the bodyweight, the exposure per unit bodyweight, (μg/kg bw/day) from the fragrance ingredient in each product is calculated for each day of the survey.
11. The subject's aggregate exposure (μg/day, mg/kg bw/day) from all products used is calculated for each day of the survey.

For exposure per unit surface area:

12. For each usage event the application site(s) is/are taken from the Kantar data, or from the assumed application sites, and then calculate the total body surface area and
13. The amount of product (g) applied to each application site is calculated for each usage event (by assuming an even application over the application site(s)).
14. Sample from distributions of fragrance in mixture concentration, C_1, and mixture in product concentrations, C_2, to calculate the concentration of fragrance in each product, C, to calculate the fragrance ingredient exposure (absolute, μg/day) from each product to each application site, for each day of the survey.
15. Dividing by the area of the application site, the fragrance ingredient exposure per unit surface area (μg/cm^2/day) from each product to each application site is calculated, for each day of the survey.
16. The subject's aggregate exposure per unit surface area (μg/cm^2/day) from all products used is calculated for each application site on each day of the survey.

For chronic or acute exposure:

17. The average exposure over the length of the survey (7 days) is taken as a measure of chronic exposure for each individual, as this is the maximum time period for which data currently exists.
18. To calculate the acute exposure, the exposure on the survey day on which the subject was most highly exposed, is taken.

These steps are repeated N times, where N is the number of subjects in the sample population chosen for that assessment. Taking the calculated exposures for the N subjects, a range of statistics (mean, min, max, standard deviation, 95th percentile etc.) is calculated for each one of the exposure types, E, using statistical weighting factors, W, which are associated with each subject in the Kantar survey. It is then possible to simulate exposure to the 'entire population' by taking each subject's weighting factor, W_i, which is

Table 8
Bodyweight scaling factors, relative to US (NHANES).

Country	Average bodyweight (kg) male	Scale factor	Average bodyweight (kg) female	Scale factor
France	77.73	0.878	66.78	0.892
Germany	84.51	0.955	71.63	0.956
Spain	73.23	0.827	62.56	0.835
Great Britain	80	0.904	67.3	0.899
US (NHANES)	88.5	1	74.9	1

Table 9
Height scaling factors, relative to US (NHANES).

Country	Average height (m) male	Scale factor	Average Height (m) female	Scale factor
France	1.741	0.988	1.619	0.999
Germany	1.78	1.010	1.65	1.018
Spain	1.761	0.999	1.655	1.021
Great Britain*	1.754	0.995	1.616	0.997
US	1.762	1	1.621	1

* The height for subjects in Great Britain are based on a weighted average heights for subjects in England, Wales and Scotland.

paired with all the exposure types for each subject, E_i, to calculate the weighted population exposure, *WPE*, thus

$$WPE = \text{StatWeighted}(W_1, E_1, W_2, E_2, \ldots, W_N, E_N) \quad (8)$$

2.10. Statistical analyses

2.10.1. Frequency of product use statistics

The format of the Kantar survey is such that each product usage event is recorded by each subject for a period of 7 consecutive days. The weekly frequency of use can then be calculated for each subject by simply counting the number of usage occasions during the survey period. The frequency of use of each of the 19 product types is calculated in this way for each of the 36,446 subjects. Subjects are also grouped by age group and gender to further analyse frequency of use patterns for the separate demographic groups.

The distribution of frequency of use data can be represented in a density plot. An open source statistical software programming language ('R') is used to produce these density plots, as well as summary statistics; number of subjects in demographic, *N*, average frequency of use per week (Mean) and standard deviation in the distribution (Stdev).

2.10.2. Product co-use statistics

It is possible to determine what percentage of the population use a specific set of product(s) over the course of the survey. Moreover, one can determine what percentage of the population use a particular product by itself or indeed what percentage of the population don't use any particular product at all. Using this logic, an open source statistical software programming language ('R') was utilised to compare which combination of products in the Kantar survey were most used by subjects.

To express co-use and non-use patterns, a co-use combinations table was generated, similar to that used in previous aggregate exposure studies (Cowan-Ellsberry and Robison, 2009). For each subject, the combination of products that they use is determined (over the course of the survey). A sum is calculated for every product combination observed, and the combinations are listed in decreasing order of popularity within the population. For the present study, the co-use between product categories was generated, as well as use and co-use for products within their defined categories.

Table 10
Relating body parts to measureable surface areas.

Body part	Surface area	References
Scalp	1/2 Head	Based on shampoo (Api et al., 2008)
Neck	1/10 Trunk	See text
Chest	1/4 Trunk	See text
Stomach	1/5 Trunk	See text
Back	3/10 Trunk	See text
Arms	Arms – (1/4 hands)	Estimated
Wrists	1/4 Hands	Estimated
Palms	1/2 Hands	Based on shampoo (Api et al., 2008)
Intimate parts	1/100 Total body	Rule of nines (O'Sullivan and Schmitz, 2007)

3. Results

3.1. Frequency of product use

In this section, density plots are produced for all subjects in EU and US for certain products that may have an interesting co-use and/or specific demographic groupings for the same product (Fig. 2). The 'modes' of the density plots can be seen as peaks and indicate the most popular usage habits. For many of the products and demographic groups, distinct modes can be seen. For example, it is most common to observe modes at the following significant frequencies: 1 (or maybe 2) uses per week, 7 uses per week, 14 uses per week and 21 uses per week. Based on these modes, we make the following inferences; if a user applies a product 7 times a week, then we assume that they apply the product once per day, on average. Therefore, 14 uses per week implies product use of twice per day, on average and 21 times a week implies product application of three times per day, on average. Note, the distributions shown here only represent the usage patterns of consumers (i.e. subjects who used the product at least one time during the survey period).

For deodorant spray and deodorant roll-on, there is a very similar usage pattern for consumers of these products (as could perhaps have been expected) (Fig. 2a). Distributions for both products exhibit a peak at 7 times per week. It should be noticed however that for some of the demographics, the peak is significantly steeper on the right hand side than the left, which is an indication that there is a greater probability of someone using this product 5 or 6 times per week, than using the product 8 or 9 times per week (i.e. the distribution of values around the peak at 7 times per week, is skewed more towards using less than 7 times per week). The frequency of use of body spray is quite different to that of deodorant spray and deodorant roll-on. The most popular habit is to use this product about once a week – with a sharp peak seen in the frequency distribution at that value.

For toothpaste, there are distinct modes visible in the density plots for all demographics at usage frequencies of 7 and 14 times

Table 11
Absolute application site surface areas.

Body part	Surface area	References
Face	1/2 Head – 28.8 cm^2	Api et al. (2008); 28.8 cm^2 refers to combined surface areas of eyes and lips
Eyes	24 cm^2	Bremmer et al. (2003)
Lips	4.8 cm^2	Ferrario et al. (2000)
Mouth	212cm^2	Collins and Dawes (1987) and Ferrario et al. (2000)
Behind ears	36 cm^2	Estimated based on expert judgement
Underarms	200 cm^2	Bremmer et al. (2003)

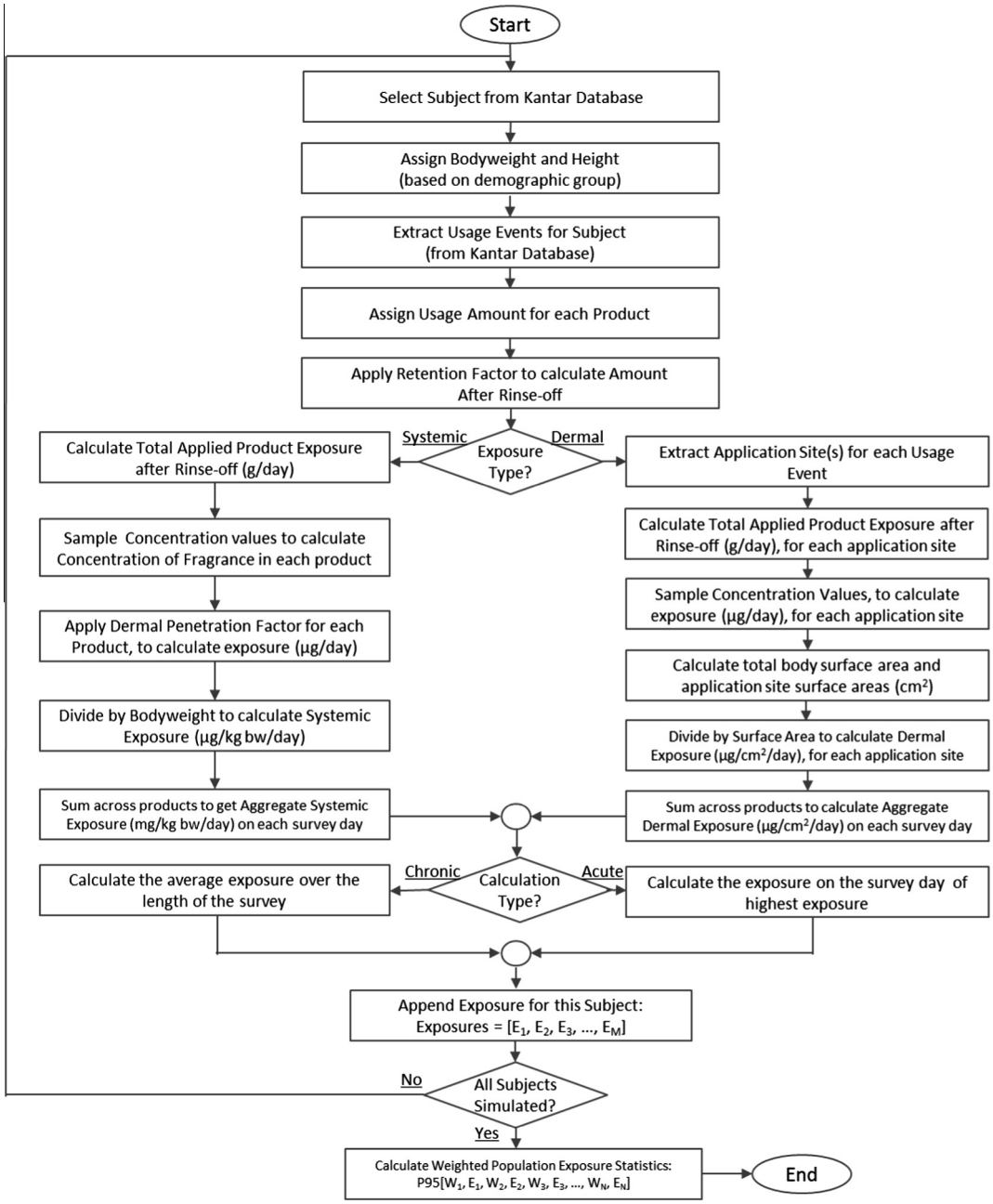

Fig. 1. Simulation method flow chart.

per week – which corresponds to usage habits of once a day and twice a day (Fig. 2b). There are also weaker modes which are just visible at 1 and 21 times per week, showing that there is a small proportion of the population who use toothpaste once per week, and three times per day, respectively. The mode at 7 times per week (once a day) is highest for the '18–34 years' demographic group, and the mode at 14 times per week (twice a day) is lowest for this demographic.

Mouthwash and face moisturiser habits were also compared for the total population and three distinct modes can be seen for mouthwash use: once a week, once a day, and twice a day (Fig. 2c). There is also a very small peak in the density plot near a weekly use of 21 times (3 times per day). Interestingly, the usage frequency of face moisturiser is very similar to that of mouthwash. Again, distinct modes are seen at 1, 7 and 14 uses per week.

The frequency of use of these lipstick and liquid makeup foundation appears very similar, perhaps indicating that consumers use these products together (Fig. 2d). An interesting feature of these distributions is the quite broad peak in the distribution which tends to occur between 4 and 7 uses per week – with a sharp fall off after 7 uses per week. Importantly, the users of these products tend to use them either once a week or once a day.

It was found that the frequency of use of body lotion (mass) and body lotion (prestige) is also very similar, showing that users tend to consume these either once a week or once a day (Fig. 2e). However, it can also be seen that there a significant portion of the population who also use these product approximately 4–5 times a week.

It was found that hair styling had quite different usage habits here between males and females, especially for the youngest age group, '18–24 years' (Fig. 2f). For males, the distribution is bi-modal, but almost flat between 1 and 7 uses per week. For females, the main peak at approximately 1 time per week is much more dominant. In the 18–34 age group, the mean usage frequency

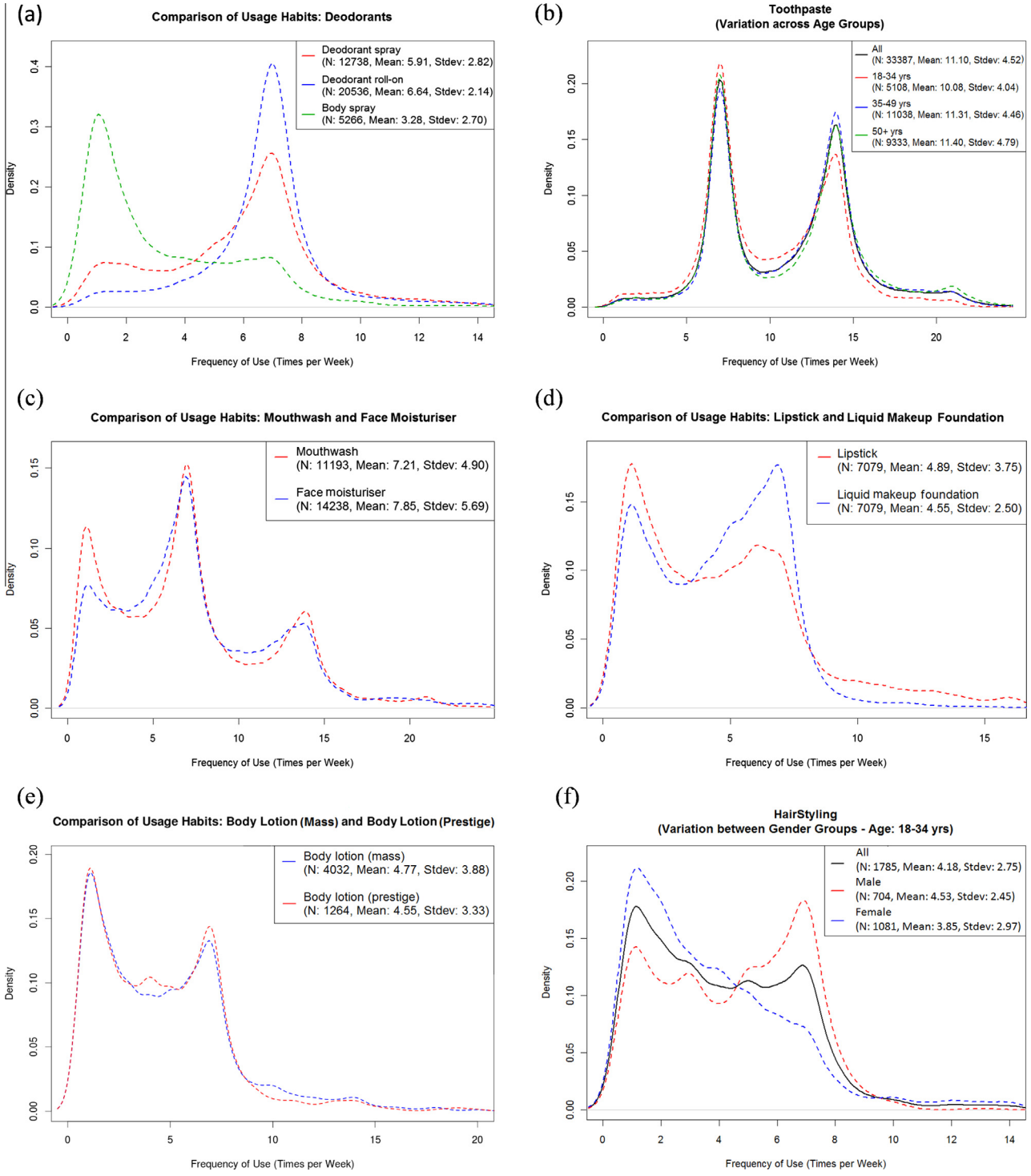

Fig. 2. Comparison of product usage habits for all subjects in EU and US in the form of density plots: (a) deodorants, (b) toothpaste across age groups, (c) mouthwash and face moisturiser, (d) lipstick and liquid makeup foundation, (e) body lotion (mass) and body lotion (prestige), (f) hair styling habits between males and females.

for males is 4.5 times per week, and for females it is 3.8 times per week.

3.2. Co-use by product category

From the Kantar data it is possible to determine the co-use and non-use statistics of the subjects. The top 20 co-use combinations of product categories for the total population (US and EU regions combined) is presented in Table 12. It can be seen that the most popular combination for the total population is deodorant, oral care, shower products. Thus 19.22% of the subjects in the Kantar surveys used a combination of deodorant product(s) (deodorant spray/deodorant roll-on/body spray), oral care product(s) (toothpaste/-mouthwash) and shower products (shower gel/shampoo/rinse-off conditioner). Other combinations occurred to a lesser extent.

As might be expected, patterns of co-use differed between genders (not tabulated here). For example, the combination of deodorant, oral care, shower products was the most popular in males (29.22%), whilst in females the most popular combination was deodorant, oral care, cosmetic styling, hydro-alcoholics, shower

products, moisturisers (13.86%). Only 0.64% of males used products from all 7 product categories, but the figure in females was much higher at 7.17%.

3.3. Co-use by products within a product category

The co-use of individual products within the defined categories were also examined (Table 13). The co-use habits within the body lotion category are quite clear. Firstly, the vast majority (81%) of subjects don't use any body lotion. As a result, only 11% use a mass market product, and 3% use a 'prestige' product. A very tiny fraction of people reported the use of both 'mass market' and 'prestige' products with the survey period.

The combined fraction of subjects who just use either deodorant spray or deodorant roll-on is quite high at 77%. The proportion of people that use both deodorant spray and deodorant roll-on is relatively very small at 2%. This indicates that people tend to use either deodorant spray or deodorant roll-on, but not both. The situation for body spray is quite different; 10% of people use body spray in addition to at least one of the other products here, with only 1% using body spray by itself. And so, it appears that the tendency is to use body spray as a compliment to one of the other two deodorant products. It is worth noting that the relative popularity of deodorant roll-on to deodorant spray is very different for the EU and US regions. In EU, roughly 30% of people only use deodorant roll-on, and 30% only use deodorant spray. In US region, almost 80% of people only use deodorant in a non-spray form, and just 5% only use deodorant spray.

The vast majority of the population use oral care products, with toothpaste being used by 93% of people – 27% of whom compliment it with the use of mouthwash. Only about 2% of people use mouthwash but not toothpaste and 5% of the people use no oral care products at all.

Cosmetic styling products are not used by 58% of the population, and within this category hair styling is the most commonly used product. Lipstick and liquid makeup foundations are also used in combinations, but at a lower percentage (5%). There is a similar co-use pattern found with hydro alcoholics where the majority of subjects do not use any hydro alcoholic product (56%). Similarly, the co-use pattern for hydro alcoholics shows each of the individual products (eau de toilette, eau de parfum, after shave) are reasonably popular by itself, but the co-use of any two or more of these products is quite low (<2%).

The co-use pattern for shower products (shower gel, shampoo, and rinse-off conditioner) shows that the vast majority of subjects (84%) use (at least) shampoo, which can be seen for the cumulative statistic for all combinations of products including shampoo. A significant proportion of people complement the use of shampoo with at least one of the other products (shower gel, rinse-off conditioner). The use of shower gel by itself is relatively low (7%) – this product is much more commonly used in combinations with one of the other products. For rinse-off conditioner, less than 1% uses this product by itself.

Moisturisers show a significant amount of non-use among the total population (65%), with 26% using face moisturiser on its own, and 6% complimenting their face moisturiser with hand cream, where 2% of the population using hand cream by itself.

Table 12
Top 20 product category co-use combinations (total population).

Product combination	% Of subjects	% (Cumulative)
Deodorant, oral care, shower products	19.22	19.22
Deodorant, oral care, hydro-alcoholics, shower products	11.78	31.00
Deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturisers	8.07	39.07
Deodorant, oral care, cosmetic styling, shower products	6.77	45.84
Deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products	5.36	51.20
Deodorant, oral care, cosmetic styling, shower products, moisturisers	4.20	55.40
Body lotion, deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products, moisturisers	3.99	59.39
Deodorant, oral care, hydro-alcoholics, shower products, moisturisers	3.98	63.36
Body lotion, deodorant, oral care, cosmetic styling, shower products, moisturisers	3.82	67.19
Deodorant, oral care, shower products, moisturisers	3.35	70.53
Oral care, shower products	3.31	73.85
Deodorant, oral care	2.54	76.39
Body lotion, deodorant, oral care, shower products	2.17	78.55
Body lotion, deodorant, oral care, cosmetic styling, shower products	1.98	80.54
Body lotion, deodorant, oral care, shower products, moisturisers	1.36	81.89
Oral care, hydro-alcoholics, shower products	1.28	83.17
Body lotion, deodorant, oral care, cosmetic styling, hydro-alcoholics, shower products	1.20	84.37
Deodorant, oral care, hydro-alcoholics	1.10	85.46
Body lotion, deodorant, oral care, hydro-alcoholics, shower products	1.01	86.47
Body lotion, deodorant, oral care, hydro-alcoholics, shower products, moisturisers	0.94	87.41

4. Discussion

It was the goal of the present study to establish a database of cosmetics and personal care product use data for the analysis of fragrance ingredient exposure from multiple products (aggregate exposure). Estimating exposure from various products allows a better understanding of the products that contribute to overall exposure in the representative population. The market study of 36,446 subjects across EU and US was a valuable source of information on usage habits. To the authors' knowledge, this study has constitutes the most comprehensive survey of habits and practices data for personal care and cosmetics applied to the area of consumer product exposure.

The integration of real habits and practice data of consumer product use, with product consumption logged by the hour for each day of the week means that true co-use data could be extracted for specific demographics. The significant size of the population, including weighting factors, meant that reliable (stable) statistics could be extracted for the sample population as shown in a concurrent publication (Safford et al., 2015). Moreover, the product application sites for most products in the survey allow the investigation of consumer product exposure per unit surface area. Since the Kantar data did not record amounts of product use per occasion, nor the subjects' exact body measurements, it was necessary to combine data from other sources to probabilistically estimate the likely amount an individual in the survey would have used and their body measurements, based on their demographics.

The combination of 'big data' and probabilistic analyses presents the safety assessor with a good estimate of the aggregate exposure within a population by choosing the relevant statistics. This is a significant departure from the method of deterministic modelling, where a high end conservative exposure from each product is simply added to estimate the exposure to a person. Such methods do not represent realistic aggregate exposure to members of a population.

As with all models of this type the accuracy of the results obtained reflect the reliability of the data used. Despite making full use of the available data, there remain a number of data gaps

Table 13
Co-use statistics on per subject basis, for products within categories, and for the total population. Note, the percentages were rounded to nearest whole number.

Product category	Product combination	% Of subjects	% (Cumulative)
Body lotion	(no product)	81	81
	Body lotion (mass)	11	92
	Body lotion (other)	5	96
	Body lotion (prestige)	3	99
	Body lotion (mass), body lotion (prestige)	1	100
Deodorant	Deodorant roll-on	59	59
	Deodorant spray	17	77
	(no product)	10	87
	Deodorant roll-on, body spray	6	92
	Deodorant spray, body spray	4	96
	Deodorant spray, deodorant roll-on	2	99
	Body spray	1	100
	Deodorant spray, deodorant roll-on, body spray	<1	100
Oral care	Toothpaste	66	66
	Toothpaste, mouthwash	27	93
	(no product)	5	98
	Mouthwash	2	100
Cosmetic styling	(no product)	58	58
	Hair styling	16	74
	Lipstick	5	80
	Liquid makeup foundation	5	85
	Lipstick, liquid makeup foundation	5	90
	Lipstick, liquid makeup foundation, hair styling	4	94
	Liquid makeup foundation, hair styling	3	97
	Lipstick, hair styling	3	100
Hydro alcoholics	(no product)	56	56
	Eau de parfum	15	70
	Eau de toilette	14	84
	After shave	13	97
	Eau de toilette, eau de parfum	2	99
	Eau de toilette, aftershave	1	100
	Eau de parfum, aftershave	<1	100
	Eau de toilette, eau de parfum, aftershave	<1	100
Shower products	Shampoo	32	32
	Shampoo, shower gel	27	59
	Shampoo, rinse-off conditioner, shower gel	14	73
	Shampoo, rinse-off conditioner	12	84
	(no product)	8	93
	Shower gel	7	100
	Rinse-off conditioner, shower gel	<1	100
	Rinse-off conditioner	<1	100
Moisturisers	(No product)	65	65
	Face moisturiser	26	91
	Face moisturiser, hand cream	6	98
	Hand cream	2	100

which inevitably means that certain assumptions needed to be made in the model. The main assumptions are as follows:

- The habits and practices of the 36,446 subjects in the Kantar surveys are representative of their respective countries.
- The habits and practices of the 4 countries: Great Britain, France, Spain and Germany are representative of the wider EU population.
- Where application site is not recorded for US subjects, the usage habits are the same as EU subjects.
- Where no application site was stated in the data, the most likely application sites were considered representative, for example rinse-off conditioner is applied to the scalp and palms of the hands.
- Where no application site option was provided in the US survey, the application sites described in the EU survey were also representative of the US.
- The equation and parameters taken from the EPA Exposure Factors Handbook provide accurate estimates the surface area of body parts using weight and height.
- The proportions of larger body parts used to derive constituent parts (e.g. a scalp is half a head, a neck is 1/10 of a trunk) are accurate estimates.
- Amount per use distributions obtained from the clinical studies in Scotland provide a good representation for all EU countries, taking into account the appropriate scaling factors, which are based on amount of product sold.
- The retention factors (Api et al., 2008) are representative of how much a product remains on the skin/ in the mouth after application.
- The retention factor used for the palms when exposed during product application (e.g. when applying body lotion), is assumed to be the same as for every other part of the body.
- When a product is applied to a body part – it is spread evenly over all of that body part.
- There is no correlation between amount per use and body surface area, or between amount per use and body weight.

The aforementioned assumptions will influence the exposure results and in most cases, and due to the conservatism of the assumptions, may lead to overestimation. Nevertheless, since conservative assumptions were used this is consistent with what is typically used in risk assessment in order to ensure protection of human health.

4.1. Future Work

The data, models and software presented in the present study show potential as a means of estimating exposure to ingredients in products, such as fragrances. If the concentrations of fragrances and ingredients present in the consumer products described in the present study are known, the database and model enables calculation of aggregate exposure to these fragrances and ingredients in European and US populations.

A number of extensions to the model are recommended. Since many of the products under study are potentially inhaled, the incorporation of an inhalation model to account for inhalation for these types of products is required. Fragrance materials are used in various household products and air care products (as are several other ingredients in personal care products and cosmetics), so the database would need to be extended to include these additional product categories. Also, some fragrance materials are chemically identical to some flavouring materials also used in food products, and many other chemicals are present in both consumer products and food simultaneously. Therefore, it would be it is necessary to expand the Creme RIFM Model to include a food consumption model for exposure to flavours and other chemicals, thus allowing the estimation of aggregate exposure to both fragrances and flavours, as well as other ingredients. It would be beneficial to include other European countries as well as other parts of the world such as Asia.

Conflict of interest

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

Transparency Document

The Transparency document associated with this article can be found in the online version.

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