



Uncertainty estimation of exposure factors for consumer products based on various sample sizes

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ABSTRACT

Usage patterns of consumer products (CP) must be determined for accurate exposure assessments. The purpose was to quantitatively estimate the uncertainty in exposure factors of CP according to various sample sizes. The uncertainty was calculated based on exposure factors of 3,333 participants representing the Korean population referred to as the 'parent population'. Small subsamples of participants randomly selected from the parent population were used to evaluate the exposure factors of 13 CPs. Exposure factors were compared with the corresponding values from the parent population. For all exposure factors, the ratio of the mean values of the 75th percentile of the subsamples to the values of the parent population became closer to 1 as the subsample size increased. For frequency of use factor, the ratio was between 0.9 and 1.1 with sample size of 100 except household bleach and trigger-type bathroom cleaner. For amount of use factor, the ratio was between 0.9 and 1.1 with sample size of 100 except body wash, household bleach, and glass cleaner. These results showed the quantitative uncertainty of exposure factor estimations according to various sample sizes. A sample size of at least 100 subjects should be collected for estimation of exposure factors for most CP.

1. Introduction

Exposure assessment of consumer products (CPs) is important because these products may contain hazardous chemicals that can cause a wide range of adverse health effects, ranging from acute symptoms to chronic diseases (Nazaroff and Weschler, 2004; Wolkoff et al., 1998). Exposure assessment of CPs is usually based on exposure scenarios. Indirect assessment of CPs requires exposure factors, such as the frequency, amount, and duration of product use. These exposure factors have previously been obtained by survey, behavioral observation, or activity models (Parmar et al., 1997; Slob and Krajnc, 1994).

Exposure can be estimated by mathematical expressions describing relationships among exposure factors in an exposure scenario, and the outcomes of exposure assessment can be affected by uncertainties of exposure factors. Uncertainty in exposure factors can result from measurement errors, including random errors and systemic bias, and from use of surrogate data, misclassification, random sampling error, and non-representativeness (EPA, 2011; Nazaroff and Weschler, 2004); uncertainty in exposure assessment is fundamentally related to a lack of knowledge about the exposure factors.

Sufficient data on exposure factors are often needed to reduce

uncertainty (EPA, 2011). However, this is difficult to achieve because obtaining such data is costly and takes a long time. Exposure factor estimates have often been based on small sample sizes. In a study in the United States, 1,030 participants were surveyed regarding the frequency of use of thirty products, but data on the amount and duration of use were not collected (Wu et al., 2010). In a study in the Netherlands, data on the frequency and amount of use of 53 products were collected from a minimum of 32 and maximum of 516 participants per product, and a minimum of 6 and maximum of 301 participants per product, respectively (Biesterbos et al., 2013). However, the duration of use was not investigated. In a study in French, usage patterns of nail cosmetics were obtained from 1,052 participants (Ficheux et al., 2014). However, data on the amount and duration of use were obtained from between only 32 and 97 participants per product.

Uncertainty in the exposure factors according to CPs usage patterns could be attributable to small sample sizes. Therefore, uncertainty due to small samples should be accounted for when considering the quality of an exposure assessment. The purpose of this study was to estimate the uncertainty in exposure factor of CPs according to sample size. The uncertainty was calculated based on the exposure factor data of 3,333 participants representative Korean population.

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Table 1
Characteristics and percentage of usage for the thirteen consumer products.

Products	Container type	Formulation	The percentage of the user (%)	The number of the user
Shampoo	Pump	Liquid	97.2	3,239
Dishwashing detergent	Pump	Liquid	82.2	2,741
Body wash	Pump	Liquid	69.1	2,302
Hair conditioner	Pump	Liquid	62.2	2,072
Household bleach	Bottle	Liquid	56.4	1,881
Facial cleanser	Tube	Cream	51.6	1,719
Fabric deodorizer	Trigger	Liquid	36.1	1,204
Bathroom cleaner (Bottle)	Bottle	Liquid	20.8	693
Bathroom cleaner (Trigger)	Trigger	Liquid	18.3	609
Toilet rim cleaner	Tube	Liquid	17.7	590
Mold stain remover	Trigger	Liquid	16.0	532
Glass cleaner	Trigger	Liquid	14.4	480
Floor cleaner	Bottle	Liquid	13.3	442

Reorganized the previous report (KNIER, 2012).

2. Methods

Data on three exposure factors (frequency of use, amount of use, and duration of use) of 13 CPs were obtained from 3,333 participants in 2,500 households. The survey methodology was described in detail in a previous study (Park et al., 2015). Briefly, the survey was conducted in 15 metropolitan areas and provinces in South Korea. A total of 2,500 households were recruited, with consideration given to the proportion of the population of each province relative to the total population. The households surveyed in each province were selected randomly. Only those householders aged 15 years or older were surveyed. Face-to-face interviews were conducted in June and July of 2012. Researchers visited each household to conduct the interviews. The survey population was henceforth referred to as 'parent population'. The characteristics of the 13 CPs are presented in Table 1. The exposure factors for each product were obtained from between 442 and 3,239 participants depending on products. This survey was approved by Institutional Review Board from Graduate School of Public Health in Seoul National University (7-2012-04-09), and informed consent was obtained from all survey subjects.

To analyze the variation in three exposure factors by sample size, seven different-sized samples of participants were randomly selected from the parent population ($n = 4, 12, 20, 60, 100, 150, \text{ and } 200$). The three exposure factors based on small samples of participants randomly selected from the parent population were compared with the corresponding values from the parent population. Five exposure factor percentiles (50th, 75th, 85th, 95th, and 99th) were compared. For the sample sizes of 4 and 12, only the 50th and 75th percentiles were compared with those of the parent population due to the absence of the 85th, 95th, and 99th percentile values. For sample sizes of 20 and 60, only the 50th, 75th, 85th, and 95th percentile values were included in the comparison due to the absence of the 99th percentile value. The subsamples were resampled 10,000 times. The description of resampling and comparing exposure factors is presented in Fig. 1.

The exposure factor percentiles of the subsamples and parent population were calculated for all 13 CPs. The mean values of the resampled 75th percentiles of each exposure factor for a given subsample were compared with the corresponding 75th percentile values for the parent population, to yield the exposure factor ratio.

R software (version 3.3.2; R Development Core Team, Vienna, Austria) was used to conduct the resampling, and to calculate the mean and range of the three exposure factors for the 13 CPs, and the differences in exposure levels between subsamples and the parent population.

3. Results and discussion

3.1. Exposure factors of CPs in the parent population

The number of users, medians and ranges of the exposure factors for the parent population are shown in Table 2. Among the 3,333 participants, the percentage using shampoo was the largest (97.2%), and the percentage using floor cleaner was the lowest (13.3%). The most frequently used products were dishwashing detergent and facial cleanser (median of two uses per day). The use frequency of glass cleaner was the lowest (median of approximately two times per month). The amount used per application was the highest for bottled bathroom cleaner, toilet rim cleaner, and floor cleaner and the lowest for facial cleanser. Trigger-type bathroom cleaner, bottled bathroom cleaner, household bleach, dishwashing detergent, and floor cleaner had the longest duration per application, while fabric deodorizer had the shortest duration.

3.2. Comparison of exposure factors between the randomly selected samples and the parent population

The exposure factor ratios for frequency, amount, and duration of use are described in Figs. 2–4. Overall, the ratios became closer to 1 as sample size increased. The ratios of the 50th, 85th, 95th, and 99th percentiles approached 1 as sample size increased (Supplementary materials).

Regarding the frequency of use factor, as shown in Fig. 2, the ratios for shampoo, dishwashing detergent, body wash, hair conditioner, facial cleanser, and toilet rim cleaner were between 0.9 and 1.1 even with a sample size of only 4. The ratios for bottled bathroom cleaner and glass cleaner were between 0.9 and 1.1 in small sample sizes of 12. The ratio for fabric deodorizer was between 0.9 and 1.1 with sample size of 60. The ratio for mold stain remover and floor cleaner were between 0.9 and 1.1 with a sample size of 100. For household bleach and trigger-type bathroom cleaner, the ratios were higher than 1.1 even with a sample size of 200.

Regarding the amount of use factor, as shown in Fig. 3, the ratios for shampoo, hair conditioner, fabric deodorizer, bottled bathroom cleaner, trigger-type bathroom cleaner, and floor cleaner were between 0.9 and 1.1 even with a sample size of 4. The ratios for facial cleanser and mold stain remover were between 0.9 and 1.1 with a sample size of 12. The ratios for dishwashing detergent and toilet rim cleaner were between 0.9 and 1.1 with a sample size of 60. For body wash and household bleach, the ratios were between 0.9 and 1.1 with a sample size of 200. For glass cleaner, the ratio was lower than 0.9 even with a sample size of 200.

Regarding the duration of use factor, as shown in Fig. 4, the ratio for bottled bathroom cleaner was between 0.9 and 1.1 with a sample size of

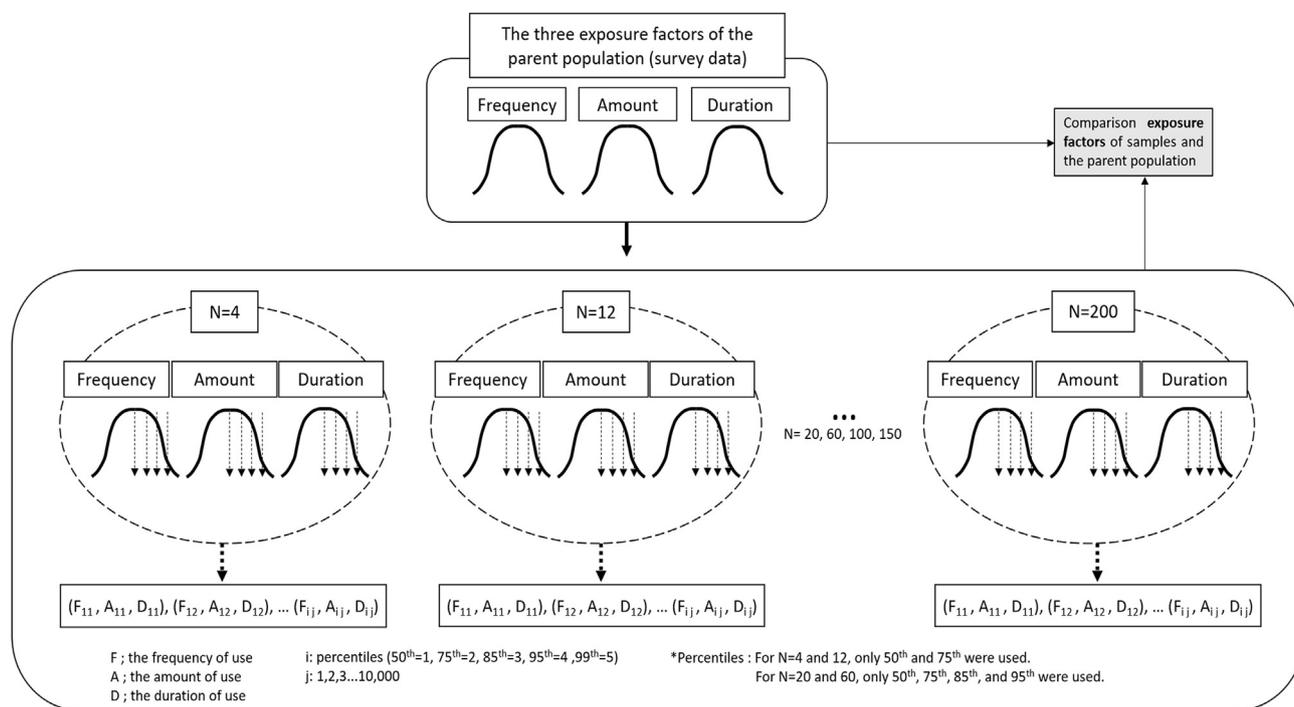


Fig. 1. Detailed description of resampling and comparing exposure factors and exposure estimates of samples and the parent population.

Table 2
Descriptive statistics of exposure factors in the parent population.

Products	No of user	Exposure factors					
		Frequency of use (event/day)		Amount of use (g/event)		Duration of use (min/event)	
		Median	Range (Min, Max)	Median	Range (Min, Max)	Median	Range (Min, Max)
Shampoo ^a	3,238	1.00	(0.14,3.00)	4.02	(0.53,12.07)	3.00	(0.33,15.00)
Dishwashing detergent	2,741	2.00	(0.03,10.00)	5.80	(1.45,43.50)	10.00	(0.33,35.00)
Body wash	2,302	1.00	(0.03,3.00)	3.95	(0.38,9.88)	5.00	(0.33,30.00)
Hair conditioner	2,072	1.00	(0.03,2.00)	3.57	(0.39,11.56)	3.00	(0.17,15.00)
Household bleach	1,881	0.14	(0.01,2.00)	5.95	(1.19,178.50)	10.00	(0.05,60.00)
Facial cleanser	1,719	2.00	(0.07,4.00)	0.60	(0.60,3.40)	3.00	(0.17,20.00)
Fabric deodorizer	1,204	0.29	(0.01,4.00)	3.36	(0.84,16.80)	1.00	(0.02,7.00)
Bathroom cleaner (Bottle) ^a	692	0.14	(0.03,4.00)	53.20	(5.32,532.00)	10.00	(0.17,30.00)
Bathroom cleaner (Trigger) ^a	604	0.29	(0.03,1.00)	6.19	(1.03,30.96)	10.00	(0.17,30.00)
Toilet rim cleaner	590	0.23	(0.03,1.00)	70.25	(10.64,532.00)	6.22	(0.08,10.83)
Mold stain remover	532	0.14	(0.01,2.00)	9.60	(1.92,76.80)	5.00	(0.17,30.00)
Glass cleaner	480	0.07	(0.01,1.00)	5.15	(1.03,30.90)	5.00	(0.05,15.00)
Floor cleaner	442	0.14	(0.02,1.43)	53.20	(10.64,532.00)	10.00	(0.17,60.00)

^a Five of the participants using trigger type bathroom cleaner, one participant using bottled bathroom cleaner, and one participant using shampoo reported times of use of zero; these data are excluded in this table.

4. The ratios for toilet rim cleaner and glass cleaner were between 0.9 and 1.1 with a sample size of 12. The ratios for shampoo, dishwashing detergent, body wash, and floor cleaner were between 0.9 and 1.1 with a sample size of 20. The ratios for facial cleanser and mold stain remover were between 0.9 and 1.1 with a sample sizes of 60. The ratios for household bleach and trigger-type bathroom cleaner were between 0.9 and 1.1 in sample sizes of 100. The ratio for hair conditioner was between 0.9 and 1.1 with a sample size of 150. The ratio for fabric deodorant was between 0.9 and 1.1 with a sample size of 200.

The exposure factor ratios of the 75th percentile values, for the various subsample sizes for all three exposure factors, were characterized by uncertainty. Overall, as sample size increased, the exposure factor values of the subsamples became closer to those of the parent population. The exposure factor ratios of all three factors for shampoo were between 0.9 and 1.1 with a sample size of 20. The ratios for dishwashing detergent, facial cleanser, and toilet rim cleaner were

between 0.9 and 1.1 in sample size of 60. For bottled bathroom cleaner, mold stain remover, and floor cleaner, the ratios were between 0.9 and 1.1 in sample size of 100. The exposure factors of some products (household bleach, trigger-type bathroom cleaner, and glass cleaner) had significant error until the sample size reached 200.

The uncertainty of the default exposure factor values in previous studies could be estimated, assuming that the exposure factor distributions were similar to our data. For dishwashing detergent, the default values for the frequency, amount, and duration of use exposure factors were determined as the 75th percentile based on the data of 45, 592 and 163 participants, respectively (Prud'Homme de Lodder et al., 2006; Weegels, 1997). These sample sizes were large enough to minimize uncertainty in the exposure factor estimations. For body wash, the frequency and duration of use factor values were obtained from a study of 86 participants (Groot-Marcus et al., 1995). Therefore, the uncertainty in the frequency and duration of use factors for body wash

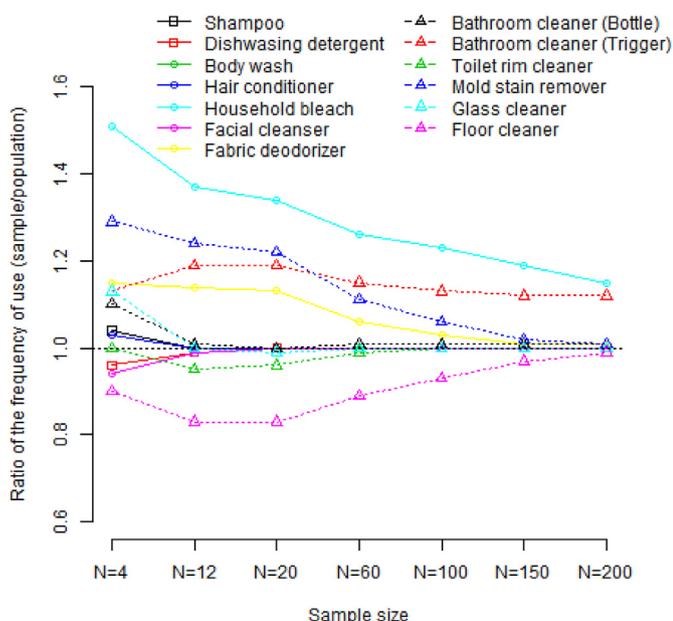


Fig. 2. Ratio of the 75th percentile of frequency of use of the sample to the parent population by sample sizes for 13 CPs.

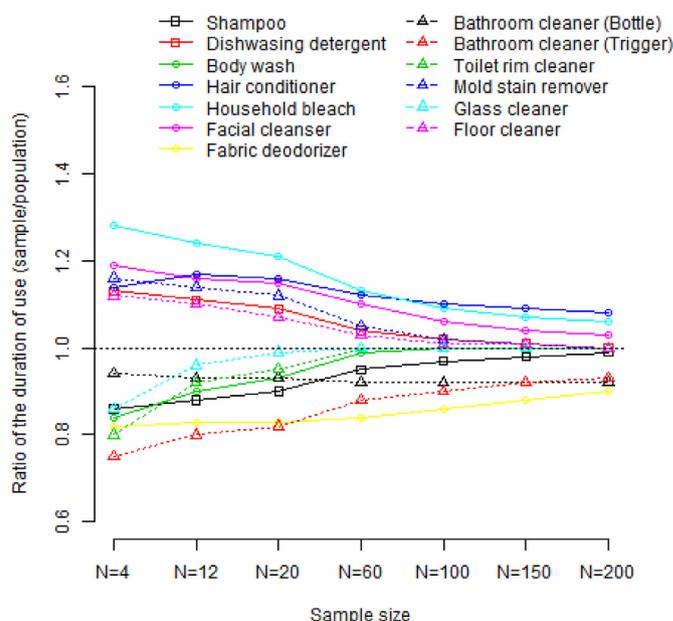


Fig. 4. Ratio of the 75th percentile of duration of use of the sample to the parent population by sample size for 13 CPs.

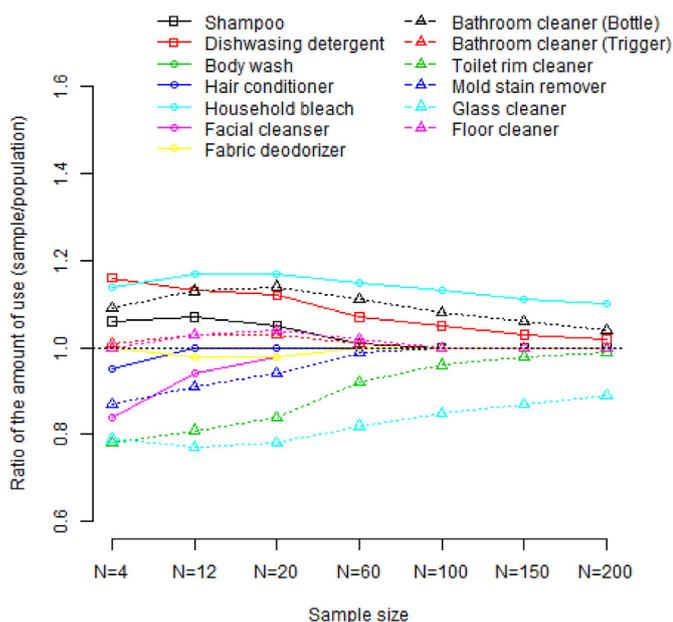


Fig. 3. Ratio of the 75th percentile of amount of use of the sample to the parent population by sample size for 13 CPs.

could be minimal. However, because the amount of use factor for body wash was derived from only 12 participants (Bremmer et al., 2006), it could have an uncertainty of more than 10%. For toilet rim cleaner, frequency of use (n = 10), amount of use (n = 12), and duration of use (n = 12) factor values were obtained from a survey (Weegels, 1997). While the uncertainty of frequency of use and duration of use factors could have minimal uncertainty, the amount of use could have an uncertainty of more than 10%. For trigger-type bathroom cleaner, amount of use value was not based on a survey. However, because the frequency of use value was derived from a survey of 2,512 participants (Eisenhower, 1987), uncertainty is likely to be relatively minimal. The duration of use factor value was derived from an RIVM study of only five people (Weerdesteijn et al., 1999), so the uncertainty therein could be greater than 10%. For glass cleaner, frequency and amount of use

factor values were based on assumptions, while the duration of use value was derived from a previous study of 10 people (Weerdesteijn et al., 1999). The uncertainty of the exposure factor values of frequency and amount of use for glass cleaner might be minimal. For household bleach, the amount and duration of use factor values were based on assumptions, while the frequency of use value was derived from a study of 10 people (Weerdesteijn et al., 1999). The uncertainty of exposure factor values of the amount and duration of use for household bleach could be greater than 20%.

Based on our findings, exposure assessors could determine the sample size required to obtain accurate exposure factors in deterministic exposure assessments. In addition, the findings provided uncertainty of exposure factors in small sample sizes. Direct application of our results should be based on assumption of similar distribution of exposure factors in different populations. Such direct application can cause error because some exposure factors may be different by country. Therefore, accurate uncertainty of exposure factors should be determined in a specific population.

Using our findings, exposure and risk assessors could conduct uncertainty analysis based on sample size for their analysis. Such uncertainty can be taken into account in decision making using deterministic exposure assessments. Based on the uncertainty analysis, they could conduct additional survey for more accurate exposure factors. The process can reduce uncertainty of exposure and risk assessment efficiently. Our findings were based on 13 CPs. The number of CPs might not be sufficient to determine impact of the distribution characteristics of exposure factors on uncertainty. Further research on characteristics of exposure factor distribution by CPs in various populations may be needed.

4. Conclusion

The degree of uncertainty in estimates of three exposure factor values for 13 CPs were quantified for small sample sizes. Overall, uncertainty decreased as sample size increased, and also differed by types of CPs. This study provided exposure factor ratios of the 75th percentile for the frequency, amount, and duration of use factors, for various subsample sizes relative to the parent population. The findings can be applied to deterministic exposure assessments. In addition, researchers can determine the sample sizes needed to obtain accurate exposure

factors estimates based on our data.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.fct.2019.110874>.

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