A Meta-Analysis of Children's Object-to-Mouth Frequency Data for Estimating Non-Dietary Ingestion Exposure

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ABSTRACT

To improve estimates of non-dietary ingestion in probabilistic exposure modeling, a meta-analysis of children's object-to-mouth frequency was conducted using data from 7 available studies representing 438 participants and ~1500 hours of behavior observation. The analysis represents the first comprehensive effort to fit object-to-mouth frequency variability and uncertainty distributions by indoor/outdoor location and by age groups recommended by the U.S. Environmental Protection Agency for assessing childhood exposures. Weibull distributions best fit the observed data and are presented by study, age group, and location. As age increases, both indoor and outdoor object-to-mouth frequencies decrease. Object-to-mouth frequency is significantly greater indoors (2 to 32 contacts/hr) than outdoors (average 1 to 9 contacts/hr). This paper compares results to a similar hand-to-mouth frequency meta-analysis. Children who tend to mouth hands indoors also tend to mouth hands outdoors; children who tend to mouth objects indoors tend to mouth objects outdoors. However, children who tend to mouth objects do not necessarily have a tendency to mouth hands. Unlike hand-to-mouth frequency, different studies affect object-to-mouth frequencies. This could be due to different definitions for object mouthing across the studies considered. The analysis highlights the need for additional object-to-mouth data (indoors and especially outdoors) for various age groups using standardized collection and analysis.

Key Words: object-to-mouth frequency, hand-to-mouth frequency, children's exposure, non-dietary ingestion, indirect ingestion

DISCLAIMER

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INTRODUCTION

Individuals, and children in particular, have the potential for exposure to toxic chemicals through hand-to-mouth and object-to-mouth exposure pathways. Chemicals can be transferred from contaminated hands, surfaces, or soil to objects such as toys, and then ingested via mouthing activity (Hubal *et al.,* 2000). Data to assess these non-dietary ingestion pathways are limited and difficult to collect. Few published studies report mouthing frequency, and the studies that have been conducted used different data collection approaches, data analysis and reporting methods, ages of children, locations, and even definitions of "mouthing" (i.e., contact with lips, inside of mouth, tongue) and "objects" (e.g., smooth surfaces, textured surfaces versus more specific object categories). Because this difference in reporting of data makes it challenging to compare results among individual studies, the available data have not been analyzed collectively for use in probabilistic exposure models.

Understanding mouthing behavior is critical to quantifying children's aggregate and cumulative exposures to chemicals. Without good information on exposure factors such as hand-to-mouth and object-to-mouth frequencies, modelers rely on uncertain default assumptions that may highly influence exposure estimates and determination of critical exposure pathways. Xue *et al.*, 2007 presented a meta-analysis of hand-to-mouth frequency data; frequency of object-to-mouth contact is also an important variable for estimating mass of chemical ingested by humans.

Generally, children's mouthing behavior is studied using both direct observation and videotaping methodologies (Zartarian *et al.,* 1997; Reed *et al.,* 1999; Freeman *et al.,* 2001; Ferguson *et al.,* 2005). Observations may be conducted by a parent, after receiving special instructions, or by a trained observer (Tulve *et al*., 2002). Videotaping to record children's behavior is done by a trained technician. Videotape footage is then translated by a person who watches the videotapes and records information by hand (e.g., number of hand-to-mouth contacts) or uses video translation software (Zartarian *et al.,* 1997; Black *et al*., 2005; Ferguson *et al.,* 2005). Data analyses from these studies are reported as either a frequency of contact (i.e., contacts/time) or as an exposure period (i.e., minutes). This paper focuses on frequency of object-to-mouth contact and a comparison to hand-to-mouth contact frequency (Xue *et al*., 2007); future research could include an analysis of available data for object-to-mouth duration information.

The general equation for estimating non-dietary ingestion of chemical residue via object-to-mouth contact typically involves the product of chemical residue on the object mouthed [$\mu g/cm^2$], object-to-mouth frequency [# contacts/hr], object surface area mouthed per mouthing event [cm^2], fraction of residue on the object transferred to the mouth during a mouthing event, and exposure duration [hr/day]. Thus, to enhance estimates of non-dietary ingestion in exposure assessments, reliable object-to-mouth frequency data are important. The EPA's Child-Specific Exposure Factors Handbook (U.S. EPA, 2002) recommends 16.3 contacts per hour for object mouthing frequency of 2-6 year-olds based on one study (Reed *et al*., 1999). Updated distributions reflecting all available data, including estimates for more refined age groupings and indoor vs. outdoor locations, could be used in probabilistic models (e.g., Calendex™, developed by Exponent, Inc., http://www.exponent.com/practices/foodchemical/calendex.html; CARES®, developed by the International Life Sciences Institute, http://cares.ilsi.org/; Lifeline™, developed by The Lifeline Group, The Lifeline Group, Inc., 2006, http://www.thelifelinegroup.org/; and SHEDS, developed by U.S. EPA's Office of Research and Development, Zartarian *et al.*, 2000, 2006) that are used to conduct children's exposure and risk assessments.

This paper is the first attempt to compile object-to-mouth frequency data from all available studies, and to conduct a meta-analysis with the following objectives:

1) examine differences across studies by age (using the EPA recommended age groupings (U.S. EPA, 2005)), gender, and indoor/outdoor location;
2) fit variability distributions to the available object-to-mouth frequency data for use in 1-D Monte Carlo exposure assessments;
3) fit uncertainty distributions to the available object-to-mouth frequency data for use in 2-D Monte Carlo exposure assessments; and
4) assess object-to-mouth frequency data needs using the EPA recommended age groupings (U.S. EPA, 2005).

METHODS

Approach for examining differences across studies by age, gender, and indoor/outdoor location

Few published studies containing object-to-mouth frequency data are available, and those available have collected and reported the data in different ways. A summary of the seven studies used in the meta-analysis for this paper are given in Table 1. For each cited study, all of the protocols and procedures related to Human Subject's Research were reviewed and approved by an independent institutional review board (IRB) and complied with all applicable requirements of the Common Rule regarding additional protections for children. While most of these involved videotaping methods, several used parents and trained observers (Tulve *et al.,* 2002; Greene, 2002). Some of the videography studies (Beamer *et al.,* 2008; AuYeung *et al.*, 2004; Hore, 2003) used video translation software developed by Stanford University (Ferguson *et al.*, 2005; Zartarian *et al.,* 1997) and others (Freeman *et al.*, 2001; Reed *et al.,* 1999) used manual recording from video observations. As mentioned in AuYeung *et al.*, 2004, mouthing of objects can be defined differently across studies (lips, inside of mouth, tongue).

Because the published studies reported summary statistics and study results in different ways and for different age groups, the authors of individual studies were contacted to obtain hourly object-to-mouth frequency data so that the data could be pooled and reanalyzed collectively in this meta-analysis, using the new EPA age groupings. For the 3 to <6 months age group, indoor object-to-mouth frequency data were available for 19 children, and no outdoor object-to-mouth frequency data were available. For the 6 to <12 months age group, there were 102 participants with indoor object-to-mouth frequency and no outdoor object-to-mouth frequency data were available. For the 1 to <2 years age group, there were 228 participants with indoor hand-to-mouth frequency and 21 with outdoor. For the 2 to <3 years age group, there were 136 participants with indoor hand-to-mouth frequency and 29 with outdoor. For the 3 to <6 years age group, there were 167 participants with indoor hand-to-mouth frequency and 53 with outdoor. For the 6 to <11 years age group, there were 15 participants with indoor hand-to-mouth frequency and 29 with outdoor. Tables 2 and 3 present the summary statistics of indoor and outdoor hand-to-mouth frequency, respectively, from the data in each of the individual studies.

No data were available in any of the studies for infants from birth to < 1 month or for 1 to < 3 months old. General linear models and mixed effects models were used to test for any statistical difference between studies, age category, gender, and location (indoor vs. outdoor). Summary statistics were obtained by study, age and location. The data were merged if there was no statistical difference among studies.

Approach for Fitting Variability Distributions

To fit variability distributions, the data from the 7 studies were compiled and put into comparable units of frequency (hourly rate) as the ratio of number of object-to-mouth contacts divided by a time interval. The denominator of that ratio was reported differently across studies: the average was ~2.2 hours of observation for outdoors and ~0.9 hours for indoors. Thus, an "observation" in Tables 2 through 7 is defined as the number of reported object-to-mouth frequency ratios, which could have different denominators. As shown in Table 1, the study periods and data collection intervals also varied across studies. A unique ID was assigned to each individual, and the data were sorted into the EPA age groupings for risk assessment (U.S. EPA, 2005) (3 to <6 months, 6 to <12 months, 1 to <2 years, 2 to <3 years, 3 to <6 years) according to the age of the child. Method of moments and maximum likelihood estimation methods were used along with visual inspection of the data, and then goodness-of-fit tests (Kolmogorov-Smirnov, Cramer-von-Mises, Anderson Darling, Chi-Square) were applied to verify the selection among a number of distributions including lognormal, Weibull, and normal distributions. Analyses were also conducted on the inter- and intra- personal variability of indoor and outdoor object-to-mouth frequency.

Approach for Fitting Uncertainty Distributions

Some exposure models (e.g., Zartarian *et al.,* 2000, 2006, 2007; Xue *et al.,* 2006; Burke *et al.,* 2001) have the option of conducting single stage Monte Carlo sampling to assess the variability in exposure or dose for a population of interest (expressed as population percentiles), or two-stage Monte Carlo sampling to evaluate uncertainty along with variability (expressed as a range of values for each percentile). Generally, an exposure model run in two-stage Monte Carlo sampling consists of generating N simulations each comprised of M iterations, which produces a family of N predicted distributions of population exposures. The entire process of a single sampling of uncertain parameters, followed by repeated sampling from the variability parameters, is referred to as a simulation (MacIntosh *et al.,* 1995).

To generate uncertainty distributions presented in this paper, the bootstrap approach described in Xue *et al*., 2006 and Xue *et al*., 2007 was used to generate 200 data pairs of Weibull distribution parameters for each age group, both for indoor and outdoor frequencies. Each pair was used for one variability run with 100 (M) variability simulations to generate 200 (N) sets of distributions (cumulative density functions) for conducting uncertainty analyses. After ranking the medians of those 200 runs, the 50^{th} and 95^{th} percentile variability distributions were selected (i.e., those distributions with the 50^{th} and 95^{th} percentile ranked medians). The 5^{th} and 95^{th} percentiles were calculated to get the ratio of the 95^{th} vs. 5^{th} for each variability run. This ratio indicates the variability (shown in the first two columns of data in Table 7). Next, the 50^{th} and 95^{th} percentiles of each of the 200 variability runs were selected, and the 5^{th} and 95^{th} percentiles were calculated for those 200 50^{th} and 95^{th} percentiles. The ratio of the 95^{th} to the 5^{th} percentile indicates the uncertainty from the selected various pairs of two hundred Weibull distribution parameters (results shown in last two columns of the data in Table 7). This process for variability and uncertainty analyses was conducted for each age group and for the two locations (indoor/outdoor).

Approach for Assessing Object-to-Mouth Frequency Data Needs

Determining where additional data would help improve the probability distributions presented was based on the sample size for each age group, study, and indoor/outdoor location and also on the uncertainty analysis.

RESULTS

Combining all those hours of behavior observation data for the 438 children ages 6 months to ~12 years old across all 7 studies, it was found that age, location (indoor vs. outdoor), and study were important for object-to-mouth frequency, but gender was not. The overall general linear model and mixed model showed that results across studies were statistically significantly different. As age increases, both indoor and outdoor object-to-mouth frequencies decrease. For both indoor and outdoor object-to-mouth frequency, interpersonal and intra-personal variability were ~58% and ~31%, respectively. Average indoor object-to-mouth behavior ranged from 2 to 32 contacts/hr, with the lowest value corresponding to the 6 to <11 year olds and the highest value corresponding to the 6 to <12 month olds and the 1-year-olds. Average outdoor object-to-mouth frequency ranged from 1 to 9 contacts/hr, with the lowest value corresponding to the 6 to <11 year olds and the highest value corresponding to the 1 to <6 year-olds (similar across 1 to <2, 2 to <3, and 3 to <6 years).

Weibull distributions were found to best fit the observed data for all analyses conducted. Figure 1 illustrates this for two of the age groups as examples. Tables 4 and 5 present the

Weibull distribution parameters and summary statistics for indoor and outdoor hand-to-mouth frequency, respectively, by age group for each of the studies. To fit Weibull distributions, a minimum sample size of 7 was used, so some participants were not included in Tables 4 and 5 for certain age groups because there were fewer than 7 data points. Fitting distributions by study and age group revealed that the mean and median were different across studies by age group for indoor and outdoor object-to-mouth frequency data.

Table 6 presents the Weibull distribution parameters and summary statistics for indoor and outdoor object-to-mouth frequency by age group, with data pooled from all studies. This table illustrates that object-to-mouth frequency generally decreases as age increases. Table 7 presents the results of the uncertainty analysis. The uncertainty was large for age groups 6 to <11 years old and 3 to <6 years old, as can be seen by studying the ratio of the 95th percentile to the 5th percentile. The results in Table 7 also reveal that the variability is much bigger than the parameter uncertainty. In comparison with other age groups, the 3 to <6 year old group had large uncertainty both for indoor and outdoor hand-to-mouth frequency. The 6 to <11 year age group had very large uncertainty for outdoor hand-to-mouth frequency. The age group of 6 to <12 months also had large uncertainty for indoor hand-to-mouth frequency. These high uncertainties are due to small sample sizes and/or differences across studies, and are consistent with the uncertainty analyses for hand-to-mouth frequency (Xue *et al.*, 2007).

Figure 2 illustrates graphically the uncertainty distributions for the 1 to <2 year and 3 to <6 year age groups examined, corresponding to the variability distributions presented in Figure 1 above. The uncertainty clouds covered well all the study data by age group. The B value ranged from 10 to 15, which indicates that we have reasonable data to define uncertainty. As discussed for Table 7, the uncertainty was large for age groups 6 to <11 years old and 3 to <6 years old; the reasons for this finding are not clear.

Figure 3 illustrates graphically the uncertainty cumulative density functions (cdfs) for 3 selected variability percentiles (5^{th}, 50^{th}, and 95^{th}) of indoor hand-to-mouth frequency for 1 to <2 year-olds and 3 to <6 year-olds, respectively. For those 200 uncertainty runs, 200 5^{th} percentiles form the bottom CDF, 200 50^{th} percentiles form the middle CDF, and 200 95^{th} percentiles form the top CDF. The 5^{th} percentiles are not stable since the values are usually very small and sometimes even zero. For the 1 to <2 year-old age group, the 95^{th} and 5^{th} percentiles for the middle CDF are 34 and 11 contacts per hour with ratio 3; the 95^{th} and 5^{th} percentiles for the top CDF are 137 and 39 with ratio 4. For the 3 to <6 year-old age group, the 95^{th} and 5^{th} percentiles for the middle CDF are 11 and 1.2 with ratio 9; the 95^{th} and 5^{th} percentiles for the middle CDF are 105 and 10.5 with ratio 5. These results indicate that the uncertainty is larger for the 3 to <6 year age group than for the 1 to <2 year age group.

Like hand-to-mouth frequency, the variability is much higher than uncertainty for object-to-mouth frequency. The correlation coefficient (r) of indoor and outdoor hand-to-mouth frequency is 0.46 and the r of indoor and outdoor object-to-mouth frequency is 0.47. However, the r of indoor hand-to-mouth and object-to-mouth, and outdoor hand-to-mouth and object-to-mouth are 0.29 and 0.35 respectively. Thus, children who tend to mouth hands indoors also tend to mouth hands outdoors; and children who tend to mouth objects indoors tend to mouth objects outdoors. However, children who tend to mouth objects do not necessarily have a tendency to mouth hands. Figure 4 illustrates the difference between hand-to-mouth and object-to-mouth contact frequencies.

DISCUSSION

Children's object-to-mouth behavior is difficult to measure for several reasons, including the following: children's contacts with surfaces and objects are frequent and intermittent; observational studies are labor-intensive for data collection and data analysis; and data analysis can be subjective (e.g., different definition of "mouthing" and "objects"). Interpretation of the results is also difficult. Some researchers express mouthing behavior in terms of frequency of occurrence (e.g., contacts per hour or contacts per minute). Others express mouthing behavior as an exposure period (i.e. minutes). This discrepancy makes it more difficult to compare results among studies. To conduct the meta-analysis presented in this paper, investigators of individual studies were contacted to provide, and in some cases reanalyze, their original study data by age, gender, and location. The uncertainty analyses in this paper only focus on parameter uncertainty, and do not account for other uncertainties from differences in study approaches and their associated reliability and validity issues.

The meta-analysis revealed that there was not a statistically significant difference in object-to-mouth frequency between genders (Xue *et al*., 2007 also found that gender did not affect hand-to-mouth frequency). However, there was a statistically significant difference in object-to-mouth behavior with regard to location (indoor versus outdoor), age groups, and studies (Xue *et al*., 2007 reported that location and age were important for hand-to-mouth frequency, but not study). Object-to-mouth frequency indoors was consistently higher for all age groups than outdoor object-to-mouth frequency. The greatest difference was observed for children 1 to <2 years old with an indoor object-to-mouth frequency 3 times higher than outdoors. As age increases, both indoor and outdoor object-to-mouth frequencies decrease. Our findings of differences between mouthing behaviors indoors versus outdoors and across ages are consistent with those discussed in some of the individual studies (Freeman *et al.*, 2001; AuYeung *et al.*, 2004; Tulve *et al.*, 2002). More reliable estimates of daily mouthing frequency should take into account these differences due to location, study, and age, as well as longitudinal estimates of mouthing behavior.

Because children can be practically observed or videotaped for only several hours in a day, available object-to-mouth frequency data are typically cross-sectional and short-term. However, exposure assessors are often interested in estimating chronic exposures. Exposure assessors typically extrapolate mouthing behaviors from several hours of observations to daily estimates using data or assumptions on the amount of time children are awake during the day and not otherwise eating. Thus, future research on children's mouthing behavior would also ideally examine longitudinal estimates within a day and over time.

The analyses in this paper represent a first effort to fit object-to-mouth frequency distributions by indoor/outdoor location, and by age using the U.S. EPA Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants (U.S. EPA, 2005). Thus, the results presented here can be used to enhance future exposure and risk assessments. This is the first comprehensive analysis to report Weibull distributions as the best fitting distribution for object-to-mouth frequency.

This paper also highlights the need for more research on mouthing behavior for children at various stages of development. For example, no data were identified for infants <3 months old. More data are also needed for outdoor object-to-mouth frequency (smaller sample sizes) and the 3 to <6 year age group because the uncertainty in the available data was large. Differences in object-to-mouth frequencies across available studies are most likely due to differences in definitions of object categories for data analysis. Any future efforts to collect object-to-mouth frequency should consider standardized definitions of object categories. Because collection of micro-activity data is intrusive, expensive, and labor-intensive, any new data collection efforts should use a standardized protocol for micro-activity data gathering and analysis and be carefully designed so that they can be combined more readily across studies.

This paper has focused on frequency of object-to-mouth contact. Future research to assist with estimation of dermal and non-dietary ingestion exposures could also include collection and analyses of available data for surface area of objects mouthed and for frequency of hand-to-object, hand-to-surface, and other body part-to-surface contact. The data in this paper could be used to update recommended object-to-mouth frequency values in the EPA's Child-Specific Exposure Factors Handbook (U.S. EPA, 2002) for more refined age groupings and indoor vs. outdoor locations. Such estimates could be used to refine probabilistic exposure and risk assessments incorporating the object-to-mouth pathway.

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Study	Study Location	# Participants	M:F Ratio	Participants' Age (min, mean, max) yrs.	Observation Period
Reed et al., 1999	NJ	30	0.4	1.8, 4.2, 6.2	3-7 hrs
Freeman et al., 2001	MN	19	0.42	3, 7, 12	4 hrs
Greene, 2002	TX and IL	169	0.53	0.3, 1.5, 3.0	4 hrs on 2 different days
Tulve et al., 2002	WA	86	0.5	0.8, 2.8, 5	5 to 60 mins per day for 1-6 days
Hore, 2003	NJ	10	0.6	2, 3.4, 4.6	4 hrs
AuYeung et al., 2004	CA	38	20:18	1,3.5,6	2 hrs
Beamer et al., 2008	CA	23	0.44	0.5, 1.3, 2.3	2-6 hours

TABLE 1. Summary of Object-to-Mouth Frequency Studies Used in Meta Analysis

Study	No. of Obervations	Mean	Std Dev	p50	p5	p25	p75
AuYeung et al., 2004	8	10.2	15.3	5.5	0.0	0.0	12.3
Beamer et al., 2008	23	32.2	22.8	29.4	9.4	18.0	39.5
Freeman et al., 2001	19	1.9	2.7	1.2	0.0	0.3	2.5
Greene, 2002	342	14.1	10.7	12.0	2.0	6.0	19.2
Hore, 2003	10	8.4	8.5	6.4	0.0	2.7	9.3
Reed et al., 1999	30	2.7	2.7	2.0	0.0	0.0	5.0
Tulve et al., 2002	238	29.3	35.1	18.0	0.0	4.0	41.0

TABLE 2. Indoor Object-to-Mouth Frequency (#contacts/hour) from Various Studies

p95
45.9
66.5
11.8
33.3
30.1
7.0
96.0

Study	No. of Obervations	Mean	Std Dev	p50	p5	p25	p75
AuYeung et al., 2004	38	6.6	6.7	4.6	0.0	1.1	9.9
Beamer et al., 2008	23	7.1	8.9	3.5	0.0	1.0	9.4
Freeman et al., 2001	15	0.6	1.5	0.0	0.0	0.0	0.5
Tulve et al., 2002	60	9.3	13.4	5.0	0.0	0.0	13.5

TABLE 3. Outdoor Object-to-Mouth Frequency (#contacts/hour) from Various Studies

p95
20.1
28.0
5.6
40.5

Study	Age Group	Distribution	Weibull Parameter Shape	Weibull Parameter Scale	Chi-Square	No. of Obervations
Beamer et al., 2008	6 to <12 month	Weibull	1.87	49.84	Pass	11
Beamer et al., 2008	1 to <2 years	Weibull	2.89	30.17	Pass	7
Freeman et al., 2001	6 to <11 years	Weibull	0.89	1.16	Pass	12
Greene, 2002	3 to <6 months	Weibull	0.74	9.83	Pass	19
Greene, 2002	6 to <12 month	Weibull	1.66	22.72	Pass	82
Greene, 2002	1 to <2 years	Weibull	1.45	15.91	Pass	134
Greene, 2002	2 to <3 years	Weibull	1.40	10.86	Pass	87
Greene, 2002	3 to <6 years	Weibull	1.19	7.67	Fail	20
Hore, 2003	3 to <6 years	Weibull	0.97	8.95	Fail	9
Reed, 1999	3 to <6 years	Weibull	0.76	2.58	Fail	25
Tulve et al., 2002	6 to <12 month	Weibull	2.66	81.61	Pass	9
Tulve et al., 2002	1 to <2 years	Weibull	1.22	49.29	Pass	84
Tulve et al., 2002	2 to <3 years	Weibull	0.55	17.07	Fail	41
Tulve et al., 2002	3 to <6 years	Weibull	0.53	7.87	Pass	104

TABLE 4. Indoor Object-to-Mouth Frequency (No. of Contacts/Hour)

Mean	Std Dev	p50	p5	p25	p75	p95
43.9	26.9	38.6	15.8	29.4	46.8	114.7
26.8	11.1	29.0	10.8	18.1	32.5	44.4
1.2	1.1	1.0	0.1	0.2	2.2	3.2
11.2	10.0	9.3	0.1	1.7	17.3	31.8
20.3	12.5	19.0	3.3	11.3	28.0	37.9
14.5	10.2	13.3	2.0	7.3	19.0	34.0
9.9	7.1	8.7	2.0	4.2	13.7	24.4
7.2	6.7	6.6	1.0	2.7	9.3	24.6
9.1	8.8	6.4	0.1	6.2	9.3	30.1
2.9	2.8	2.0	0.1	1.0	5.0	7.0
72.3	32.2	84.0	27.0	52.0	96.0	116.0
46.7	34.7	40.5	2.0	21.5	65.5	98.0
26.7	44.9	15.0	0.1	3.0	29.0	96.0
12.6	17.3	5.0	0.1	0.1	18.0	44.0

Weibull Distrbution by Age Group from Various studies

Study	Age Group	Distribution	Weibull Parameter Shape	Scale	Chi-Square	No. of Obervations	Mean
AuYeung et al., 2004	1 to <2 years	Weibull	1.43	8.26	Pass	7	7.5
AuYeung et al., 2004	2 to <3 years	Weibull	1.67	6.51	Pass	7	5.8
AuYeung et al., 2004	3 to <6 years	Weibull	0.77	7.03	Pass	17	8.0
AuYeung et al., 2004	6 to <11 years	Weibull	0.57	1.92	Fail	7	3.1
Beamer et al., 2008	6 to <11 years	Weibull	0.67	1.51	Pass	12	1.9
Freeman et al., 2001	6 to <11 years	Weibull	0.51	0.43	Fail	10	0.9
Tulve et al., 2002	1 to <2 years	Weibull	0.69	7.55	Pass	10	9.2
Tulve et al., 2002	2 to <3 years	Weibull	0.48	5.22	Fail	17	9.6
Tulve et al., 2002	3 to <6 years	Weibull	0.52	5.58	Pass	33	9.3

TABLE 5. Outdoor Object-to-Mouth Frequency (No. of Contacts/Hour) V

Std Dev	p50	p5	p25	p75	p95
5.5	7.9	0.7	3.8	10.2	17.5
4.0	4.1	2.0	2.6	9.9	12.8
8.4	6.1	0.1	1.5	10.6	30.3
4.4	0.8	0.1	0.1	9.1	9.9
2.4	1.0	0.1	0.1	3.0	8.0
1.8	0.1	0.1	0.1	1.6	5.6
11.2	5.5	0.1	3.0	14.0	38.0
13.1	5.0	0.1	0.1	15.0	41.0
14.4	5.0	0.1	0.1	12.0	46.0

Veibull Distrbution by Age Group from Various studies

Age Group	Distribution	Weibull Parameter Shape	Scale	Chi-Square	No. of Obervations	Mean
			INDOOR			
3 to <6 months	Weibull	0.74	9.83	Pass	19	11.2
6 to <12 month	Weibull	1.31	29.91	Fail	102	27.5
1 to <2 years	Weibull	1.02	26.82	Pass	228	26.6
2 to <3 years	Weibull	0.80	13.03	Fail	136	15.0
3 to <6 years	Weibull	0.58	6.90	Pass	167	10.1
6 to <11 years	Weibull	0.84	1.20	Pass	15	1.3
			OUTDOOR			
1 to <2 years	Weibull	0.93	8.58	Pass	21	8.8
2 to <3 years	Weibull	0.64	6.15	Fail	29	8.1
3 to <6 years	Weibull	0.55	5.38	Pass	53	8.3
6 to <11 years	Weibull	0.55	1.10	Fail	29	1.9

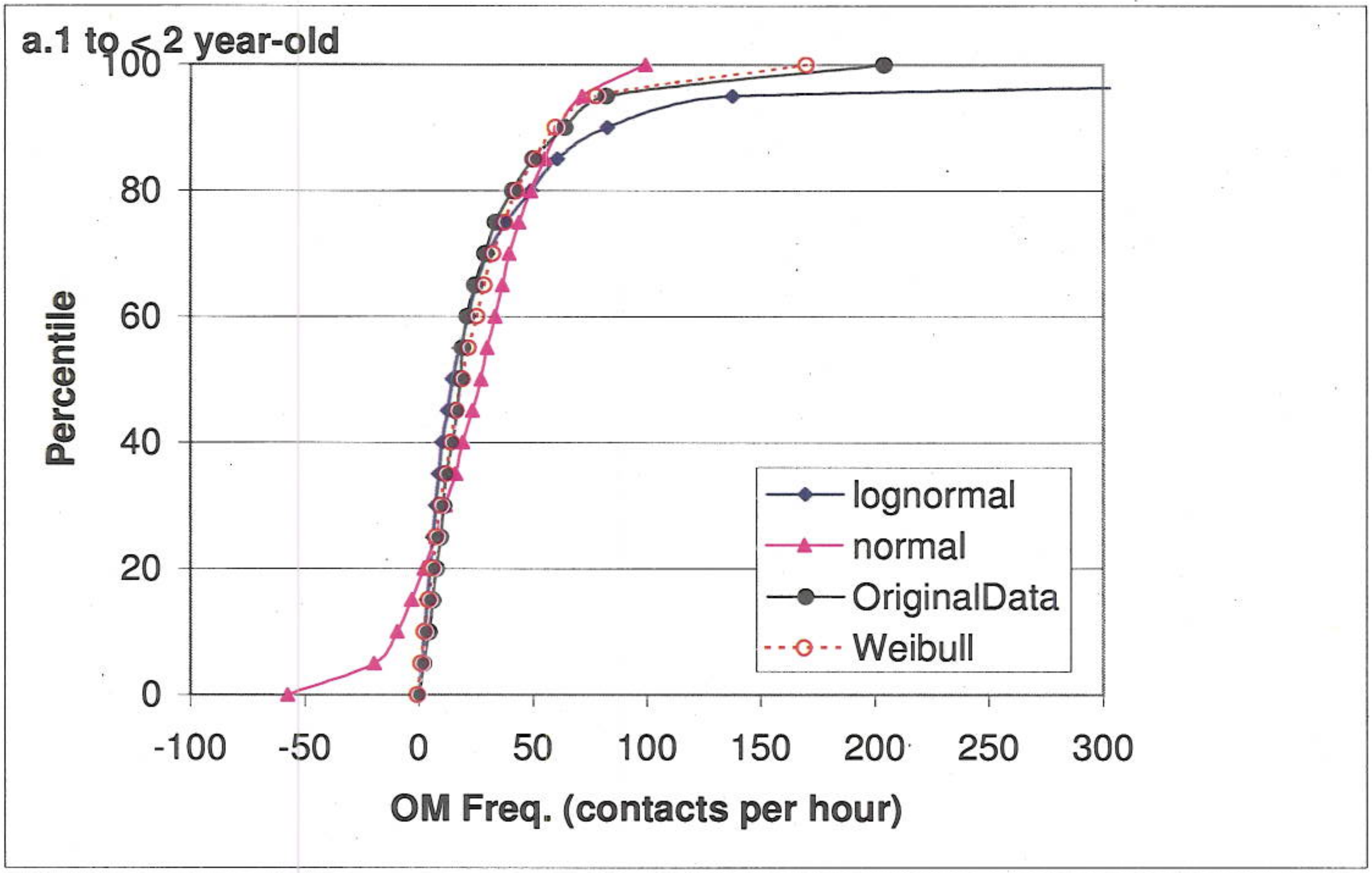
TABLE 6. Indoor and Outdoor Object-to-Mouth Frequency (No. of C

Std Dev	p50	p5	p25	p75	p95
10.0	9.3	0.1	1.7	17.3	31.8
23.0	23.7	3.7	13.3	32.3	84.0
27.4	18.2	2.0	9.5	33.7	82.0
26.3	9.5	0.1	3.9	17.1	36.0
14.8	5.0	0.1	1.0	13.0	39.0
1.2	1.0	0.1	0.1	2.5	3.7
8.8	6.0	0.1	3.8	10.8	21.3
10.5	4.6	0.1	1.5	11.0	40.0
12.4	5.0	0.1	0.1	10.6	30.3
2.8	0.8	0.1	0.1	2.0	9.1

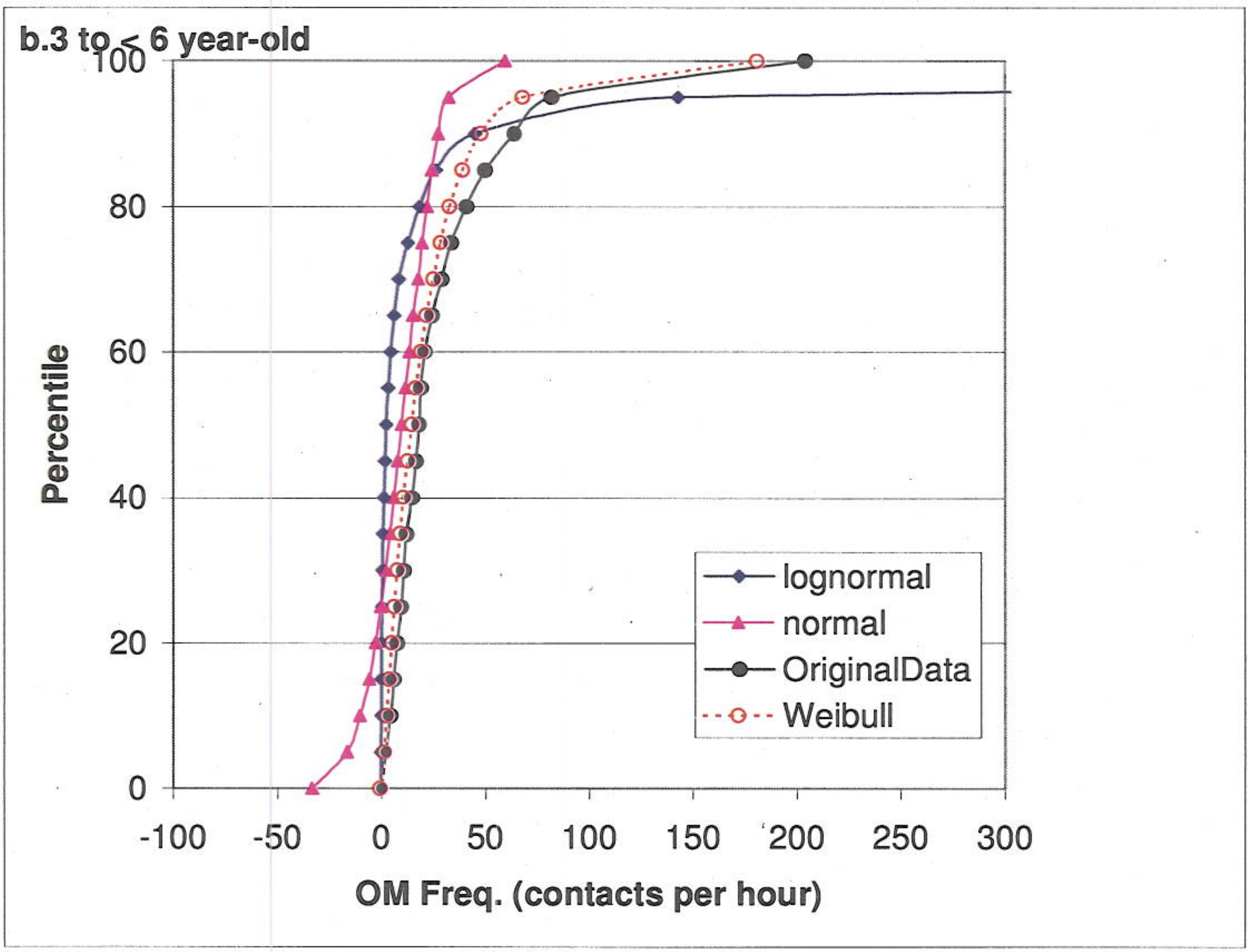
ontacts/Hour) Weibull Distrbution from Available studies

	Selected Variability Runs Ratio of 95th vs. 5th Percentile		Selected Variability Percentiles Ratio of 95th vs. 5th Percentile	
Age Group	50th Percentile	95th Percentile	50th Percentile	95th Percentile
	Indoor Object-to-Mouth Freq. (contacts/hour)			
3 to <6 months	89	28	5	4
6 to <12 month	22	6	3	3
1 to <2 years	14	12	3	4
2 to <3 years	35	46	5	4
3 to <6 years	827	196	9	10
6 to <11 years	36	21	5	5
	Outdoor Object-to-Mouth Freq. (contacts/hour)			
1 to <2 years	21	11	4	4
2 to <3 years	18	34	7	6
3 to <6 years	157	592	5	7
6 to <11 years	4394	116	6	7

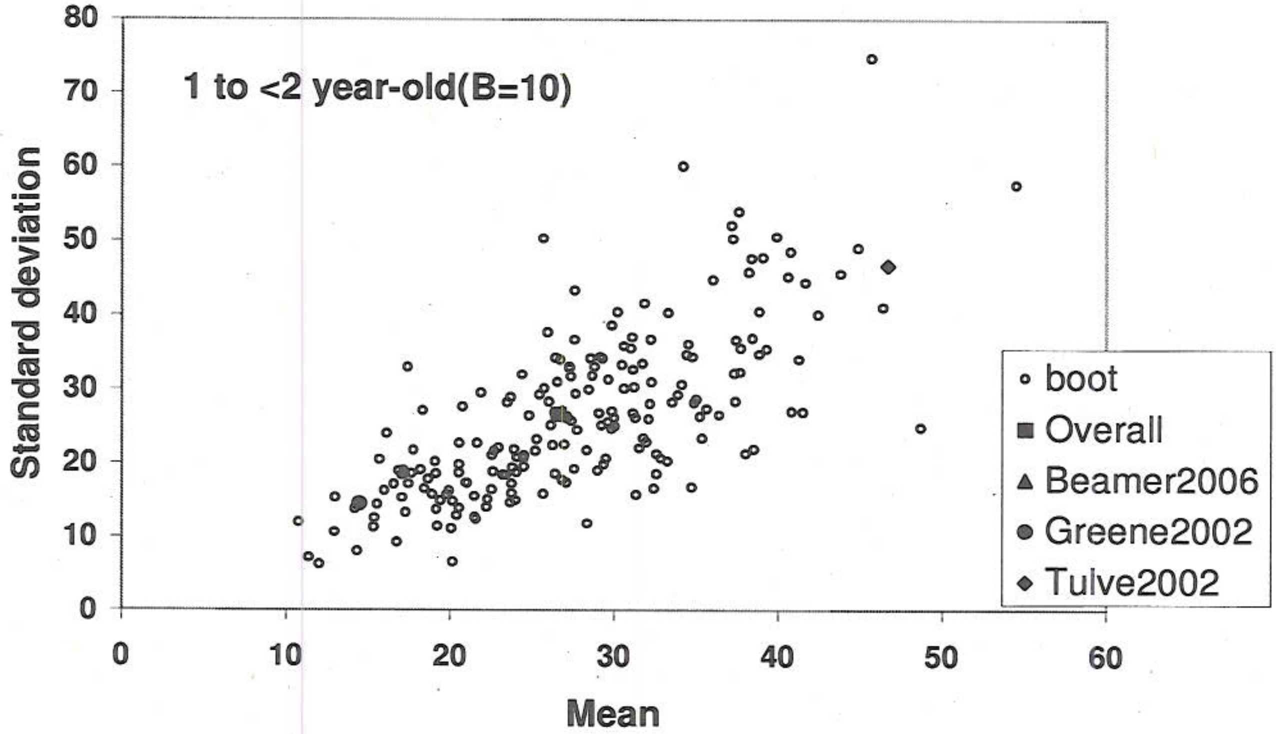
TABLE 7. Uncertainty Analyses



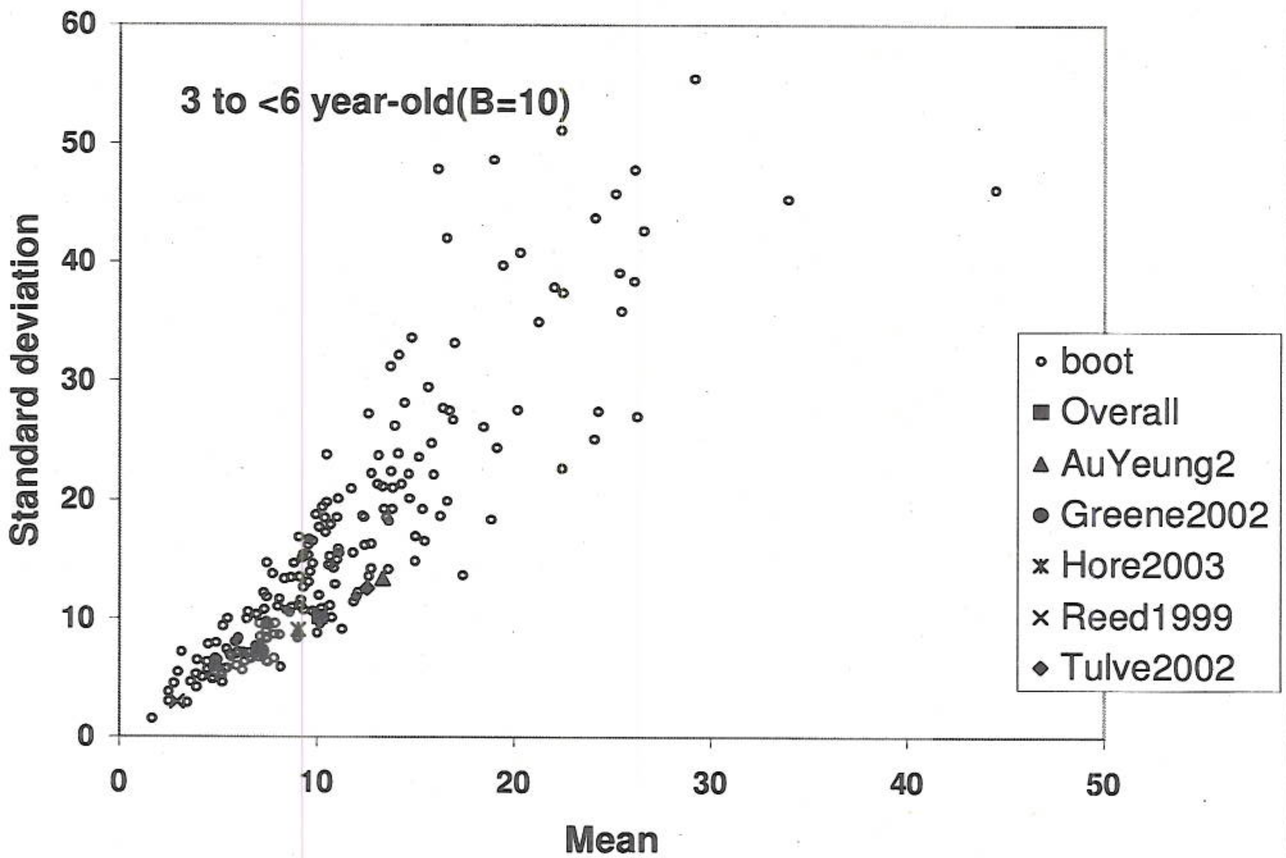
a.1 to < 2 year-old
Percentile
100
80
60
40
20
0
-100
-50
0
50
100
150
200
250
300
OM Freq. (contacts per hour)
lognormal
normal
OriginalData
Weibull



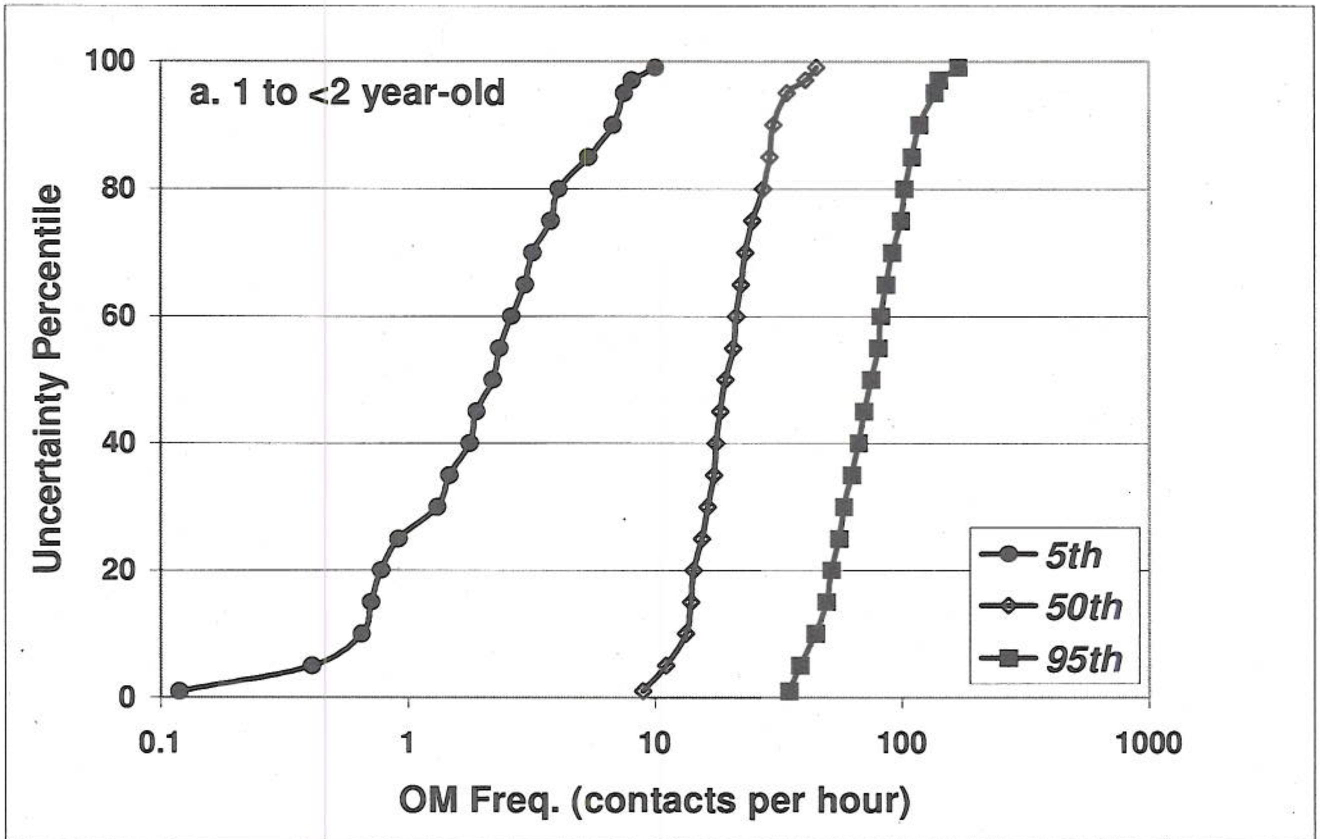
b.3 to < 6 year-old
Percentile
100
80
60
40
20
0
-100
-50
0
50
100
150
200
250
300
OM Freq. (contacts per hour)
lognormal
normal
OriginalData
Weibull

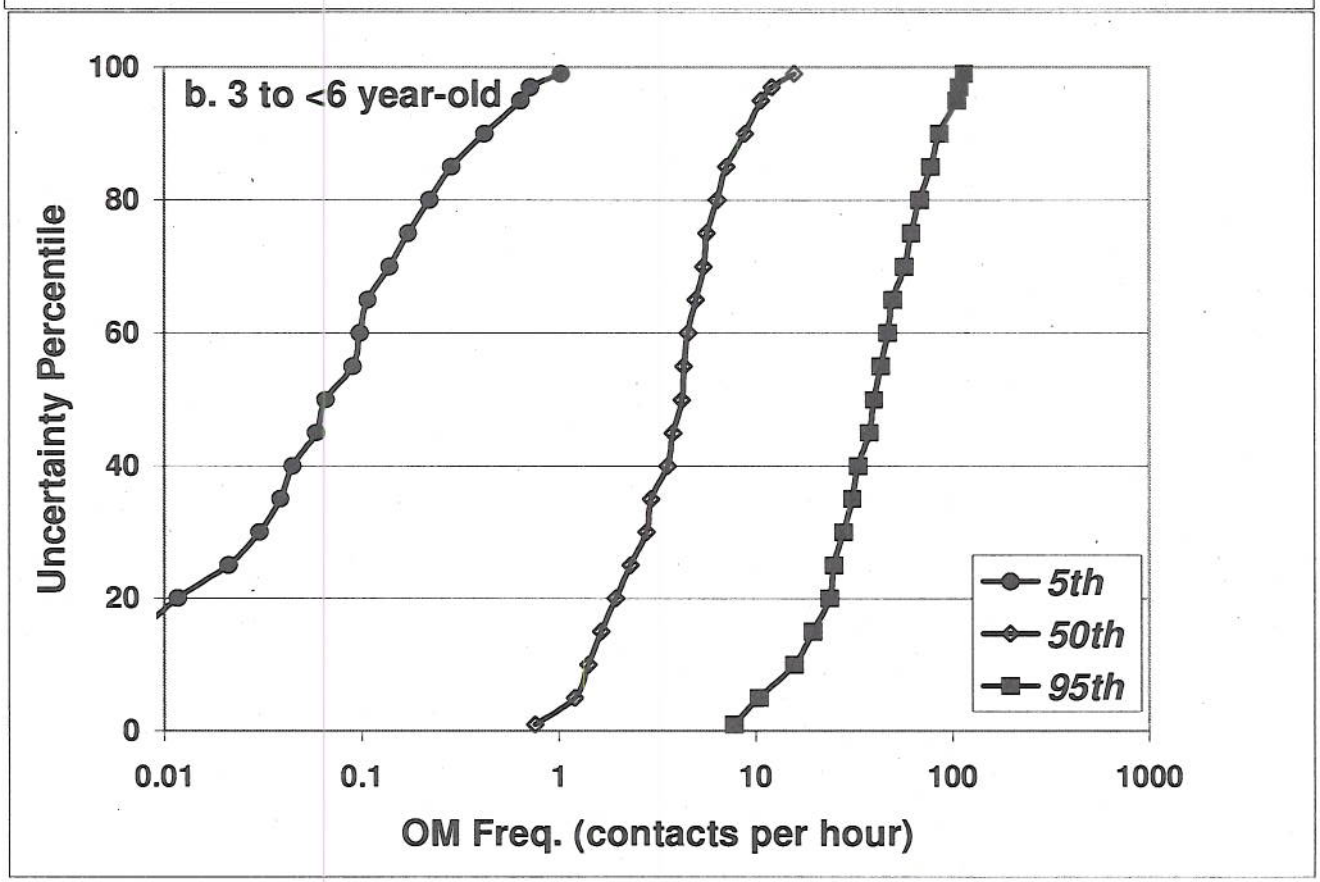


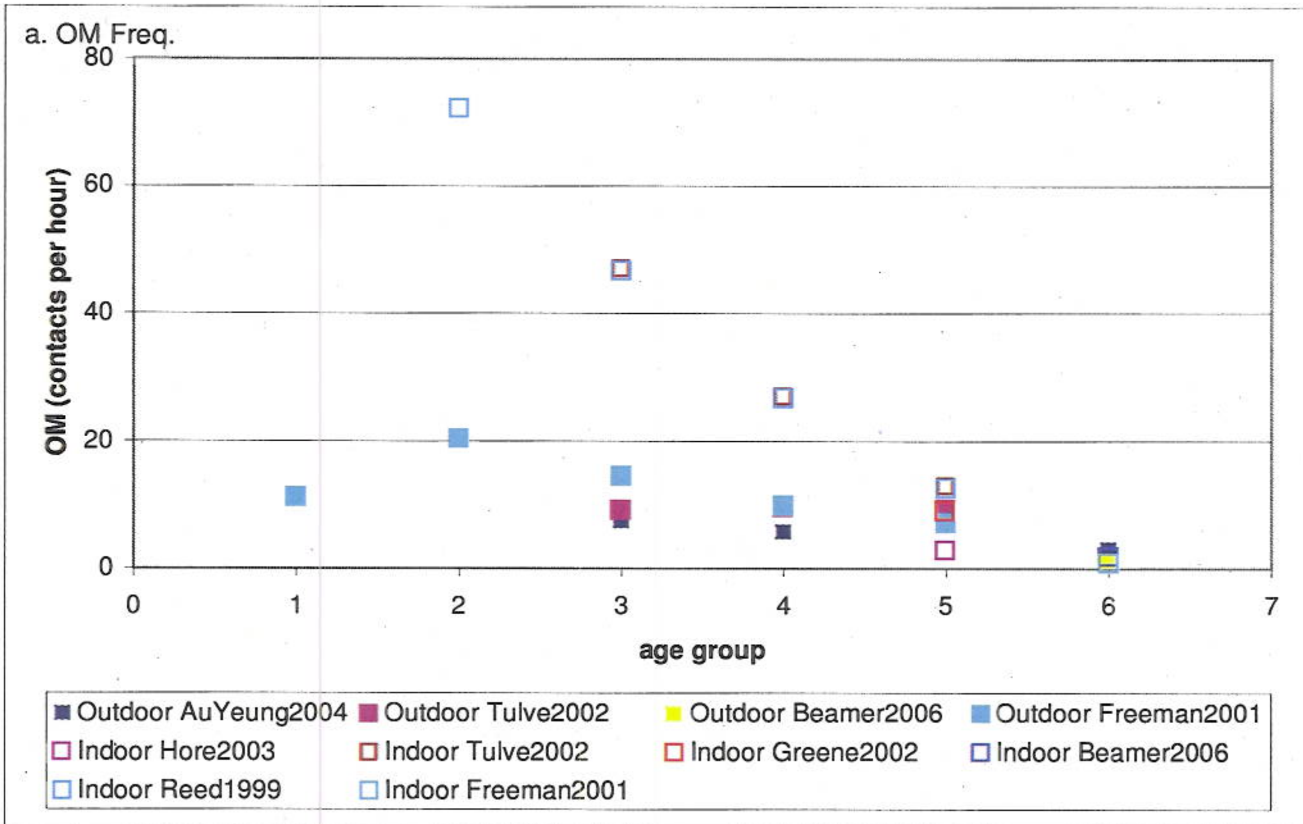
1 to <2 year-old(B=10)
Standard deviation
Mean
boot
Overall
Beamer2006
Greene2002
Tulve2002

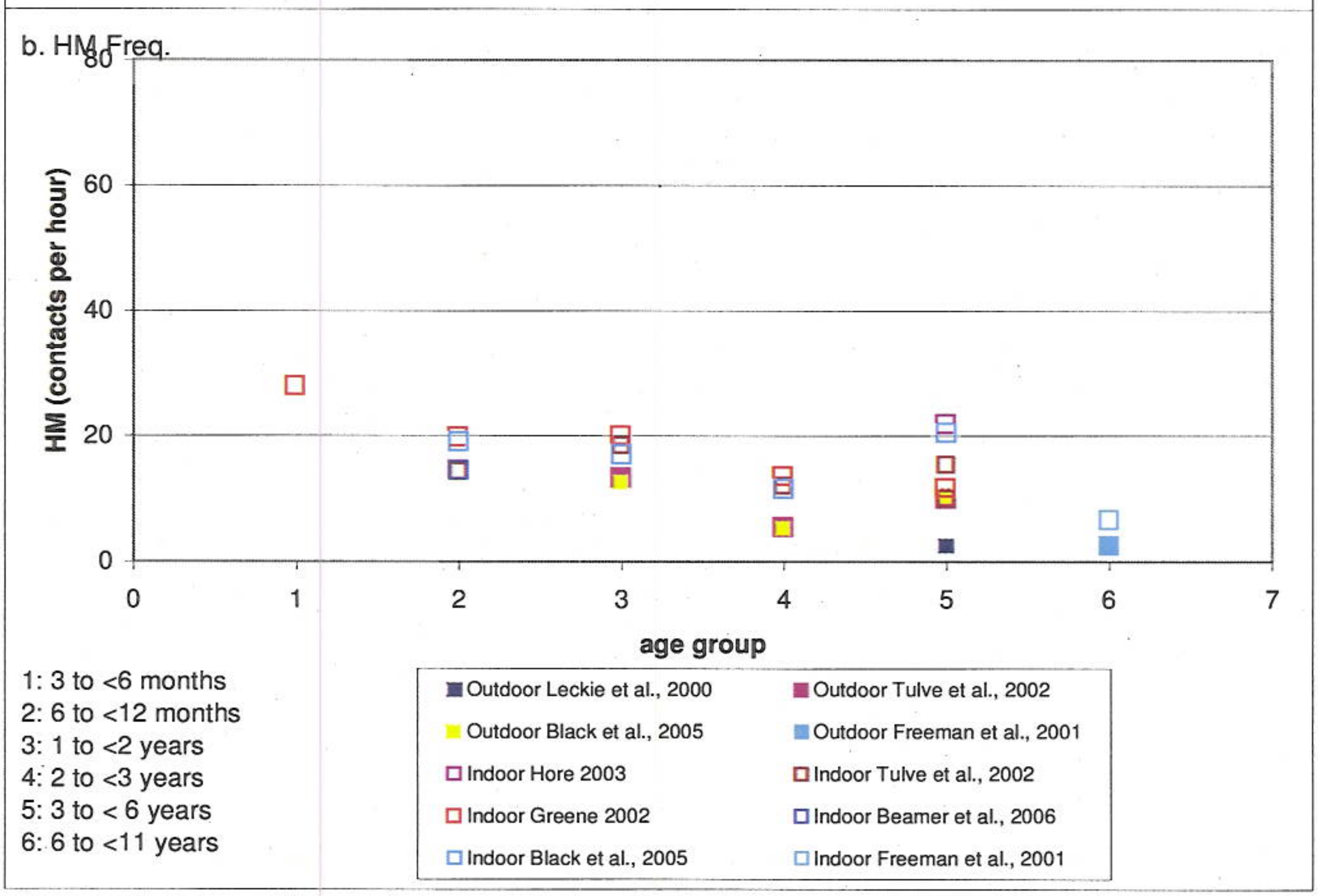


3 to <6 year-old(B=10)
Standard deviation
Mean
boot
Overall
AuYeung2
Greene2002
Hore2003
Reed1999
Tulve2002


a. 1 to <2 year-old
Uncertainty Percentile
100
80
60
40
20
0
0.1
1
10
100
1000
OM Freq. (contacts per hour)
5th
50th
95th


b. 3 to <6 year-old
Uncertainty Percentile
100
80
60
40
20
0
0.01
0.1
1
10
100
1000
OM Freq. (contacts per hour)
5th
50th
95th


a. OM Freq.
OM (contacts per hour)
80
60
40
20
0
0
1
2
3
4
5
6
7
age group
Outdoor AuYeung2004
Outdoor Tulve2002
Outdoor Beamer2006
Outdoor Freeman2001
Indoor Hore2003
Indoor Tulve2002
Indoor Greene2002
Indoor Beamer2006
Indoor Reed1999
Indoor Freeman2001


b. HM Freq.
HM (contacts per hour)
80
60
40
20
0
0
1
2
3
4
5
6
7
age group
1: 3 to <6 months
2: 6 to <12 months
3: 1 to <2 years
4: 2 to <3 years
5: 3 to < 6 years
6: 6 to <11 years
Outdoor Leckie et al., 2000
Outdoor Tulve et al., 2002
Outdoor Black et al., 2005
Outdoor Freeman et al., 2001
Indoor Hore 2003
Indoor Tulve et al., 2002
Indoor Greene 2002
Indoor Beamer et al., 2006
Indoor Black et al., 2005
Indoor Freeman et al., 2001